This is to certify that the

thesis entitled

SEISMICITY AND TECTONICS OF
THE FAR WESTERN ALEUTIAN ISLANDS

presented by

James Tyler Newberry

has been accepted towards fulfillment
of the requirements for

M.S degree in Geological Sciences

Kazuya Fujita
Major professor

Date 11 November, 1983

SEISMICITY AND TECTONICS
OF THE FAR WESTERN ALEUTIAN ISLANDS

By

James Tyler Newberry

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the Degree of

MASTER OF SCIENCE

Department of Geological Sciences

1983

ABSTRACT

SEISMICITY AND TECTONICS
OF THE FAR WESTERN ALEUTIAN ISLANDS

By

James Tyler Newberry

The present day tectonics of the Near and Komandorsky Islands (far western Aleutians) are studied using seismicity, focal mechanisms, and depth phase analysis. The Near Islands are characterized by normal faulting south of the Aleutian Ridge and shallow thrusting near the ridge. Results indicate underthrusting as far west as Ostrov Mednyy with strike-slip faulting restricted to the south of Ostrov Beringa; this disagrees with prior models which suggested strike-slip motion through the entire region. A zone of north-east striking left-lateral faulting, which may separate the Aleutian Ridge from Kamchatka, is proposed near 164.5 degrees east. Normal faulting north of the Komandorskys may be related to bouyancy of a remnant slab. Depth phase modelling indicates bulletin reported depths are too deep. Moment release calculations imply that there may not be a true seismic gap in the Komandorsky Islands.

ACKNOWLEDGEMENTS

I would like to express my appreciation to Kaz Fujita for all of his help, insight, and patience during the past several years. Thanks to him also for helping me overcome my great fear of raw fish, chopsticks, computers, Amtrak, public speaking, and professors. Thanks as well Hugh Bennett and Tom Vogel for helpful comments as members of my committee. Thanks to F. W. Cambray who unknowingly sparked my interest in matters of geology some 8 years ago via public television. Special thanks go to Seth Stein, Doug Wiens and Joe Engeln at N.U. for their exceptional hospitality and generosity and use of their seismological data collection and surface wave analysis package. Thanks to Bill Rogers for whiskey and shelter in Evanston. Thanks to Glenn Kroeger and Bob Geller for use of their synthetic seismogram program. Thanks to Norm Sleep for helpful comments and fish stories. Thanks to Klaus Jacob and Bob Engdahl for their comments and criticisms. Appreciation goes to Bill Monaghan for sharing the macroheadaches derived from microcomputing. Thanks to Ann Goulette for cartographic criticisms and to the Geography Department for the use of their digitizing facility. Special thanks go to David LaClair, whose meticulous work and keen insight laid the groundwork for this study. Thanks the the Harp Brewing Company, Elderly Instruments, and the Peanut Barrel for assisting me in efforts to keep my head on my shoulders. Most of all, thanks to the fellow students: Mike, Ben, Bruce, Dave, Bill, Gary, Jody, Cindy, Bill, Don, Soo-Meen, Dave, Mongo, Randy, and many others, past and present, whose friendship I have enjoyed.

Support was provided by Chevron Oil Company, and support and research were provided by NSF grant EAR 80-25267, and ONR contract no. N00014-8-3K-0693.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The Aleutian island arc represents a zone of convergence between the Pacific plate to the south and the North American plate to the north. This convergence is characterized by a subduction zone at which the North American plate is being underthrust by the Pacific plate which is moving in a northwesterly direction. Associated with this subduction zone is the characteristic magmatic arc, consisting of basaltic and andesitic volcanism and their associated sediments, which make up the Aleutian Island chain. Also associated with this convergence is a zone of seismicity which has been shown to be discontinuous along the length of the arc (Figure 1). The far western Aleutians constitute a zone where the relative convergence vector of the Pacific plate with respect to the North American plate changes from obliquely convergent to essentially parallel with the plate margin, as one moves westward along the arc (Figure 1).

Upon examination of the geometry of the tectonic setting, a zone of northwest striking right lateral

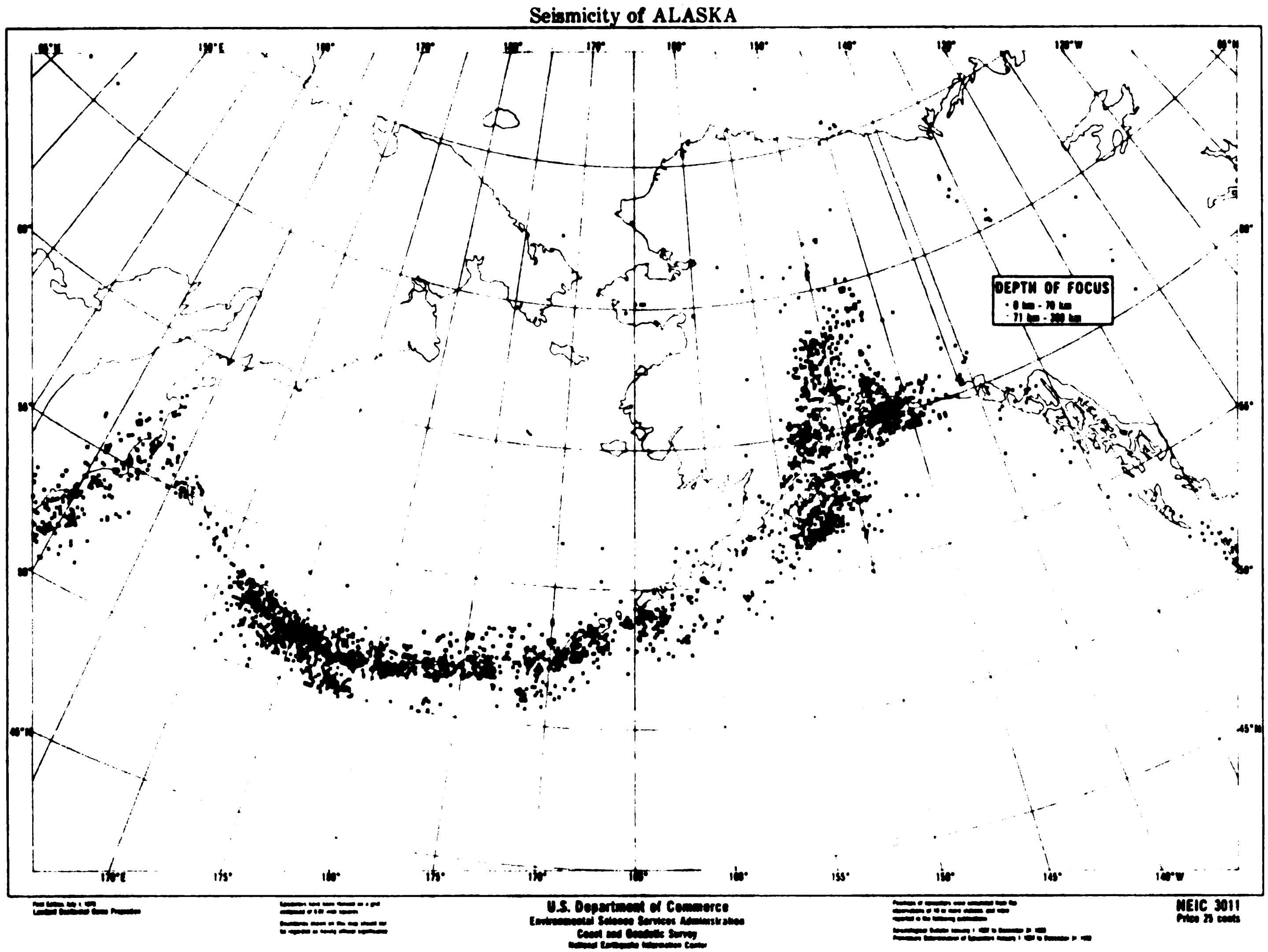


Figure 1-Seismicity of the Aleutian Arc

strike-slip faulting would be expected in the far western Aleutians. Previous work has shown that although strike slip faulting is indicated in this region, a significant number of events indicating other types of faulting occur (Cormier, 1975a). Cormier noted that the horizontal component of the slip vectors of all of the solutions maintained a uniformity toward the northwest, consistant with the direction of the regional convergence vector.

The zone of transition from oblique convergence to essentially strike-slip motion is the subject of this thesis. The objective will be to try to gain an understanding of the tectonics in the area by studying the seismicity, the nature of faulting as indicated by fault-plane solutions, and the waveforms produced by these earthquakes. This study is intended to supplement the work of Cormier(1975a) and that of Stauder(1968) in the light of several years of additional data.

GEOLOGIC SETTING

Regional Setting

The area of interest lies at the farthest western reaches of the Aleutian Island chain, between 164 degrees east and 178 degrees east, and includes the Komandorsky Islands (Beringa and Mednyy), the Near Islands (Attu, Agattu, and others), and the western Rat Islands (including Kiska). At the western boundary of the study area is the Aleutian arc - Kurile-Kamchatka arc junction which is also the site of visable termination of the Emperor Seamount chain. The Komandorsky Basin section of the Bering Sea to the north has been the subject of some attention due to its anomalously high heat flow and apparently young age (Cormier, 1975a; Rabinowitz and Cooper, 1977). Tholeiitic basalts found at DSDP site 191 (Figure 2) have been dated at 32.3 ma. (mid-Oligocene, using the time scale of Harland et al., 1982) and are postulated to be of regional extent in the Komandorsky Basin (Stewart et al., 1973). The Komandorsky Basin is bounded on the east by the Shirshov Ridge, an enigmatic bathymetric rise which has been postulated to be several things, including a remnant island arc, an ancient spreading center and a result of hot spot activity near a transform fault (Ben-Avraham and Cooper, 1981). North of the Near Islands is the Bowers Basin which is delineated by the extent of the Bowers Ridge, an arcuate

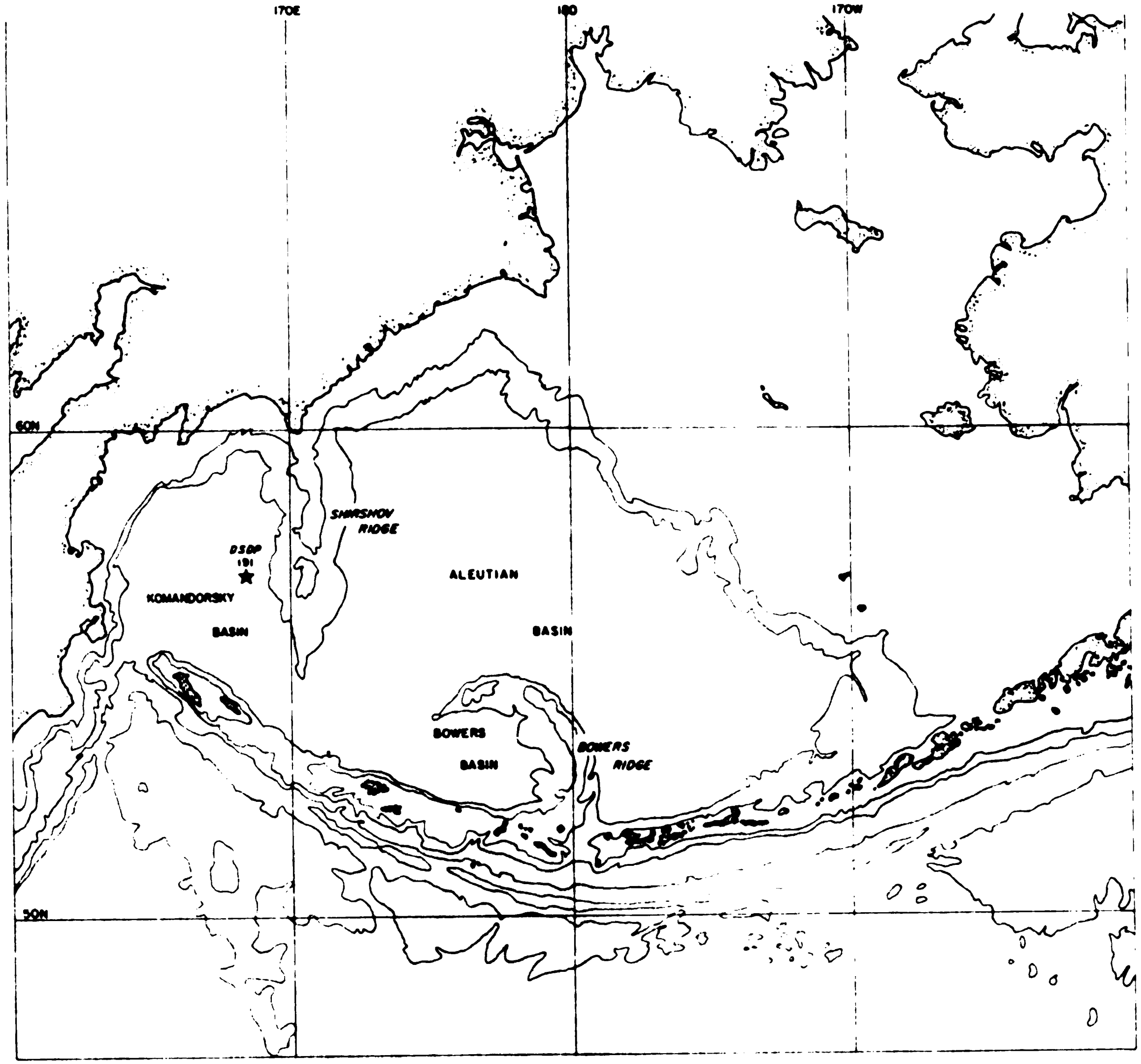


Figure 2-Basins of the Bering Sea

bathymetric feature which has been interpreted as an inactive island arc with a sediment-filled trench on its north flank (Cooper et al., 1981). It has been suggested that underthrusting activity at the Bowers Ridge occurred mainly in Mesozoic and early Tertiary time, with minor underthrusting continuing throughout Cenozoic time.

The formation of the Bering Sea-Aleutian Ridge system is currently a subject receiving considerable attention in the light of the aforementioned discoveries, along with some new and surprising paleomagnetic data in the eastern reaches of the Aleutians and Alaska. This evidence implies that much of southern Alaska and parts of the Bering Sea may have developed at more southerly latitudes and moved northward to their current position; much of this movement to have taken place continuously throughout Cenozoic time (Stone et al., 1982). The contradiction of the paleomagnetic data with the geologic data, which infers that the Peninsular terrane of southern Alaska and the Beringian margin had accreted to Alaska by the end of the Mesozoic, has yet to be resolved (Marlow and Cooper, 1983).

Geology of the Western Aleutians

Considering the enigmatic nature of the Komandorsky Basin, careful inspection of the geologic record of the western Aleutians is necessary to determine if this section of the arc is a simple continuation of the eastern section. If not, it may be taken to imply that the Komandorsky Basin is itself of allocthonous character.

The geology of the Komandorsky Islands has been quite thoroughly studied by Soviet geologists in recent years (Schmidt, 1978; Tsvetkov, 1980; Borsuk and Tsvetkov, 1980). The features noted by these geologists have been interpreted in accordance with standard Soviet geological principles, dismissing the western view of global plate tectonics (Schmidt, 1978). The descriptive elements of the Soviet literature have been extracted and are summarized in Appendix A and commented upon below.

The rocks of the Komandorsky Islands have been described in terms of six stratigraphic suites, the lower four of which have been grouped as the Komandorsky Series. The rock units found contain mainly volcanic and volcanogenic sedimentary rocks. The lowermost unit consists of basaltic pillow lavas, massive lavas, rhyolites, and tuffs. This unit has been paleontologically dated as Paleocene. The rhyolites of this unit have been suggested to be younger material (middle Oligocene, by K/Ar dating), intruding the Paleocene basalts (Tsvetkov, 1982). The rest of the Komandorsky Series is characterized by increased volumes of tuffs and volcanogenic sediments and the disappearence of pillow lavas. Plant detritus, coal, and sedimentary structures in the uppermost suite of the Komandorsky Series indicate a proximity to land and a shallow water environment.

Unconformably overlying the Komandorsky Series is the Nikol'skoye Suite, which is marked by the appearence of alkaline andesites and basalts, interpreted to be the products of shield volcanism. The unit overlying this, the Vodopad Suite, contains subaerial lava flows of basalts, andesites, dacites, and ignimbrite-like formations. These two youngest units found on the Komandorsky Islands have been faunally dated as late Oligocene to Miocene.

The pillow basalt-andesite-rhyolite assemblage, like that described for the Komandorsky Islands, has been suggested to be produced by the maturation of a young subduction zone (Ringwood, 1974). The content and form of the rocks of the Komandorsky Series appear to reflect the continuous building of a volcanic arc, from early deep-water pillow lavas to volcaniclastic rocks deposited in a shallower water environment to extrusion of andesites and dacites in subaerial conditions. The geological description implies that the arc had been built above sea level around Miocene time.

The rocks forming the Near Islands seem to reflect a similar history of early oceanic volcanism (late Mesozoic to early Tertiary), and later uplift, subaerial erosion and extrusion of andesitic and dacitic lavas, probably in middle to late Tertiary (Gates et al., 1971). Kiska Island, located on the far eastern edge of the study area, is characterized by three volcanic rock formations. The lowermost formation contains pillow basalts and pyroclastics and has been estimated to be middle Tertiary age; the determination being made by analogy to paleontologically dated rocks found on some of the Rat Islands and Amchitka (Coats et al., 1961). Resting unconformably on this formation is a unit composed of subaerial lava flows, autoclastic breccias, pyroclastic rocks, and volcanogenic sediments. This formation has been dated in a similar fashion as being of late Tertiary to early Pleistocene in age. The third geologic entity on Kiska Island is Kiska Volcano, an andesite volcano which last erupted in September, 1969 (Simkin et al., 1981)

The uniformity of geologic events across the Aleutian Ridge has been noted by DeLong et al. (1978), who correlated events as far west as the Near Islands. Examination of the data assembled by the Soviets appears to justify extention of this uniform character west to include the Komandorsky Islands. DeLong et al. (1978) describe a major event occuring around 30 million years ago (mid-Oligocene) which is expressed as an unconformity (reflecting uplift) ubiquitous to the arc and a clustering of radiometric age dates, which they ascribe to the signature of a metamorphic event. They suggest that these findings reflect the subduction of the Kula Ridge at the Aleutian Trench. A major unconformity has been described as existing between rocks of the dominantly marine volcanic rocks of the Komandorsky Series (analogous to the "Early Series" rocks described by DeLong et al.(1978) as spanning the rest of the arc) and the rocks of the Nikol'skoye and Vodopad suites (which may be analogous to the lower portion of the "Late Series" rocks). The paleontologically determined ages of the units on either side of the unconformity are consistant with the 30 million year date assigned by DeLong et al. (1978). The main notable difference between the rocks of the Komandorsky Islands and those of the central and eastern sections of the arc is the lack of Pliocene and younger volcanism in the west. The ability to correlate the rock units of the Komandorsky Islands with the rest of the Aleutian Ridge lends support to the notion that these far western islands have been part of the Aleutian arc system since its beginnings in early Tertiary time.

SEISMICITY

Magnitude and Frequency

As can be clearly seen on the seismicity map of the Aleutian arc as a whole (Figure 1) the density of epicenters is not uniform along the arc. This segmentation of seismicity has lead to the identification of several seismic "gaps" in the Aleutian arc . As many as five of these gaps have been proposed for the Aleutian arc (Figure 3, Sykes et al., 1981), one of the most "mature" of these located in the Komandorsky Islands region, from 170 degrees east to near the coast of the Kamchatka Peninsula (Jacob, 1983). This section of the far western Aleutians has not been the site of a very large earthquake (magnitude > 7.4) since 1858, although it is not clear if the record for events is complete over the last 125 years (Sykes et al., 1981).

In this study, attention was focused on the events which occurred in the far western Aleutians from 178 degrees east to 164 degrees east, with the Komandorsky Islands region receiving the most rigorous treatment. From 170 degrees east to 164 degrees east, only 211 events were reported by the International Seismological Centre (ISC) and/or the United States Geological Survey (USGS) for the time period 1964-1982; only 46 of these being of magnitude > 5.0 (mb) and only 3 of these of magnitude > 6.0 (mb).

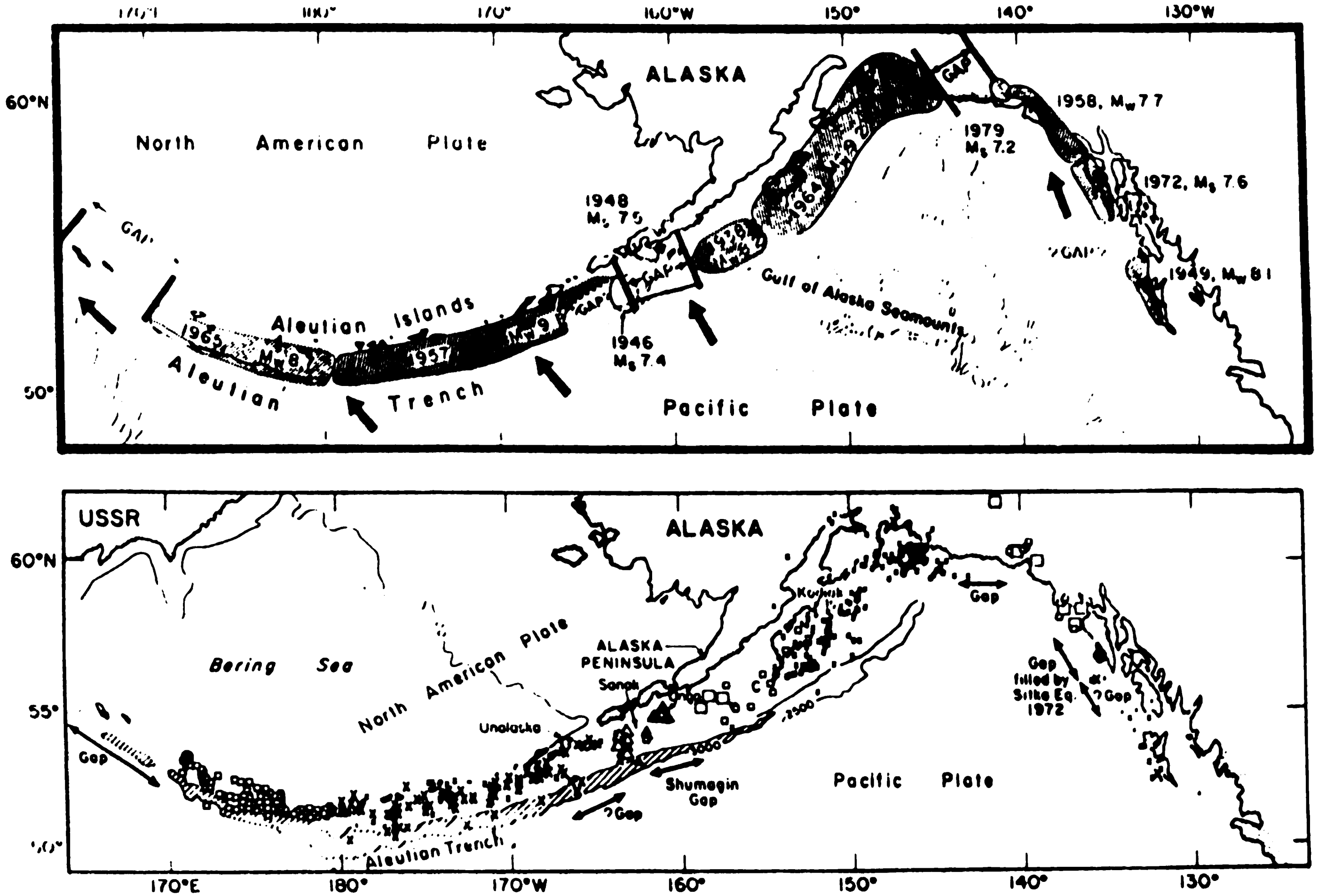


Figure 3-Seismic Gaps of the Aleutians, from Sykes et al., (1981)

It should be noted that the smaller magnitude portion of the data set is likely to be temporally biased due to detection-level changes related to closing and opening of several seismological arrays in the continental United States, Alaska and the Aleutians (Habermann, 1983).

The moment release corresponding to these events was estimated (Figure 4) using the assumption that in the lower portion of the magnitude spectrum, there is roughly a 1:1 ratio of Ms:mb (Evernden, 1975). Considering the difficulty of obtaining precise magnitudes for small earthquakes using teleseismic data, as well as the error introduced by the above assumption, these moment estimates may be viewed as more qualitative than quantitative. The relationship between moment (Mo) and magnitude (Ms) is given below:

$$\text{Log } M_o = \frac{3}{2} M_s + 15.5 \qquad \text{(Farmer, 1982)}$$

The average annual moment release in the Komandorsky Islands over the time period studied is about 1.6 x 10E24 dyn-cm with the cumulative total estimated at around 3 x 10E25 dyn-cm. To emphasize the small absolute value of this number, it should be noted that the moment release in the Great Chilean earthquake of May 22, 1960 (Ms = 8.3) was determined to be 2.7 x 10E30 dyn-cm (Kanamori and Cipar, 1974), five orders of magnitude greater than the cumulative total of nineteen years of seismic activity in the Komandorsky Islands region.

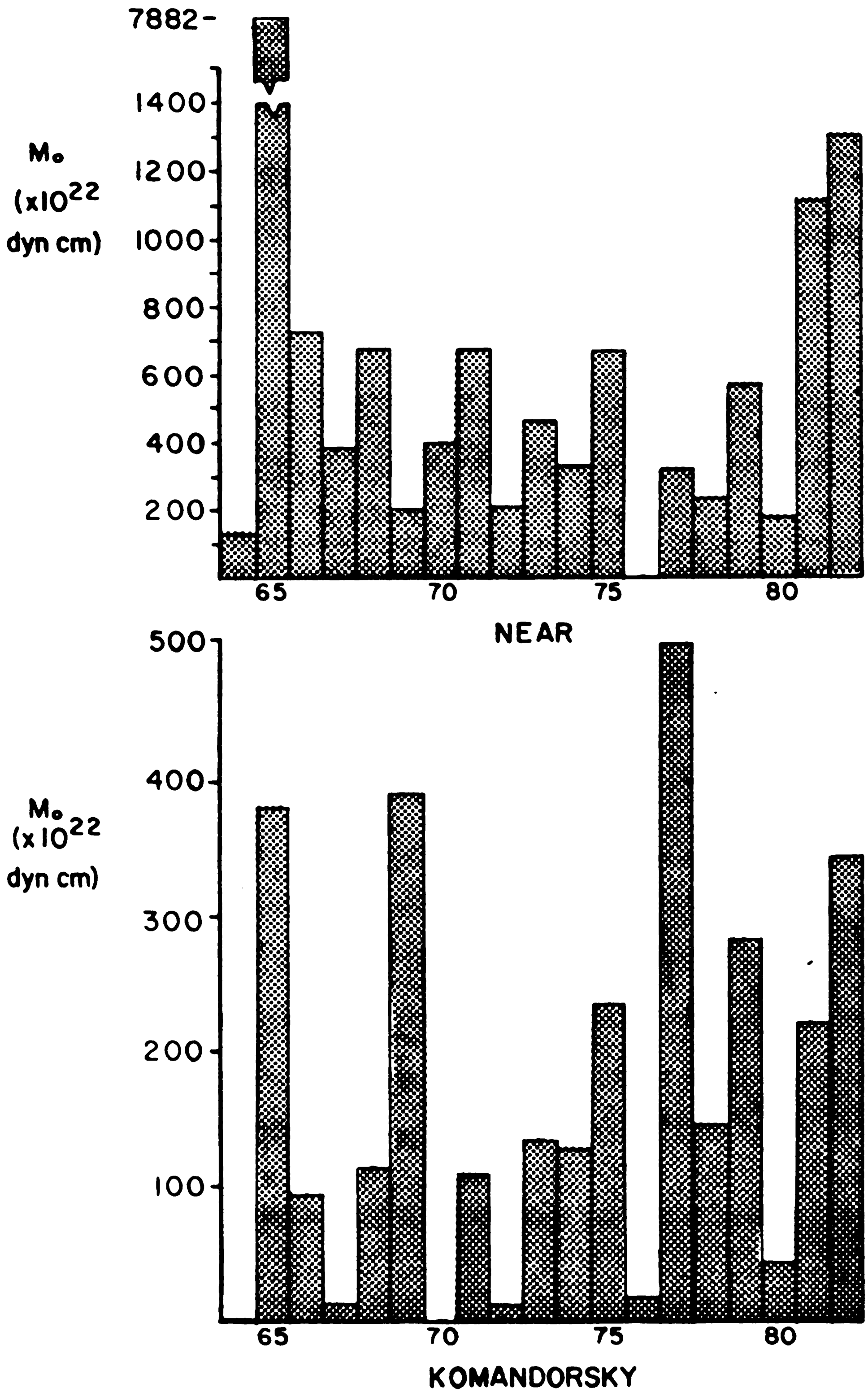


Figure 4-Annual moment release

The overall seismicity of the Near Islands is much greater, as can be observed in Figure 5. To keep the scale of the study in within managable bounds, only events which were reported by 50 or more stations were included in the base data set. This corresponds to a cutoff at magnitude 4.7 (mb), although some smaller events were included which fit the necessary criterion. The resulting set of events consists of 393 events reported by the ISC and/or the USGS ocurring in the section of the Aleutian arc between 178 degrees east to 170 degrees east during the 19 year study period. The average annual moment release (Figure 4) was estimated to be between 4.69 x 10E24 and 8.59 x 10E24 dyn-cm, depending whether or not the year 1965 is included in the averaging, since it represents the abnormally high value of moment release corresponding to the aftershocks of the Rat Island event of February 4 (Ms = 8.1). The lesser of the two values therefore more accurately represents the background seismicity of the area. The cumulative total moment released, including the year 1965, was estimated at 1.63 x 10E26 dyn-cm, a value 5.5 times that calculated for the Komandorsky Islands region to the west.

Qualitatively comparing the shapes of the histograms of Figure 4, it is clearly seen that with the exception of three years out of a total of nineteen, the year to year correspondence is very similar. The moment release of two of the anomalous years, 1969 and 1977, is dominated by a

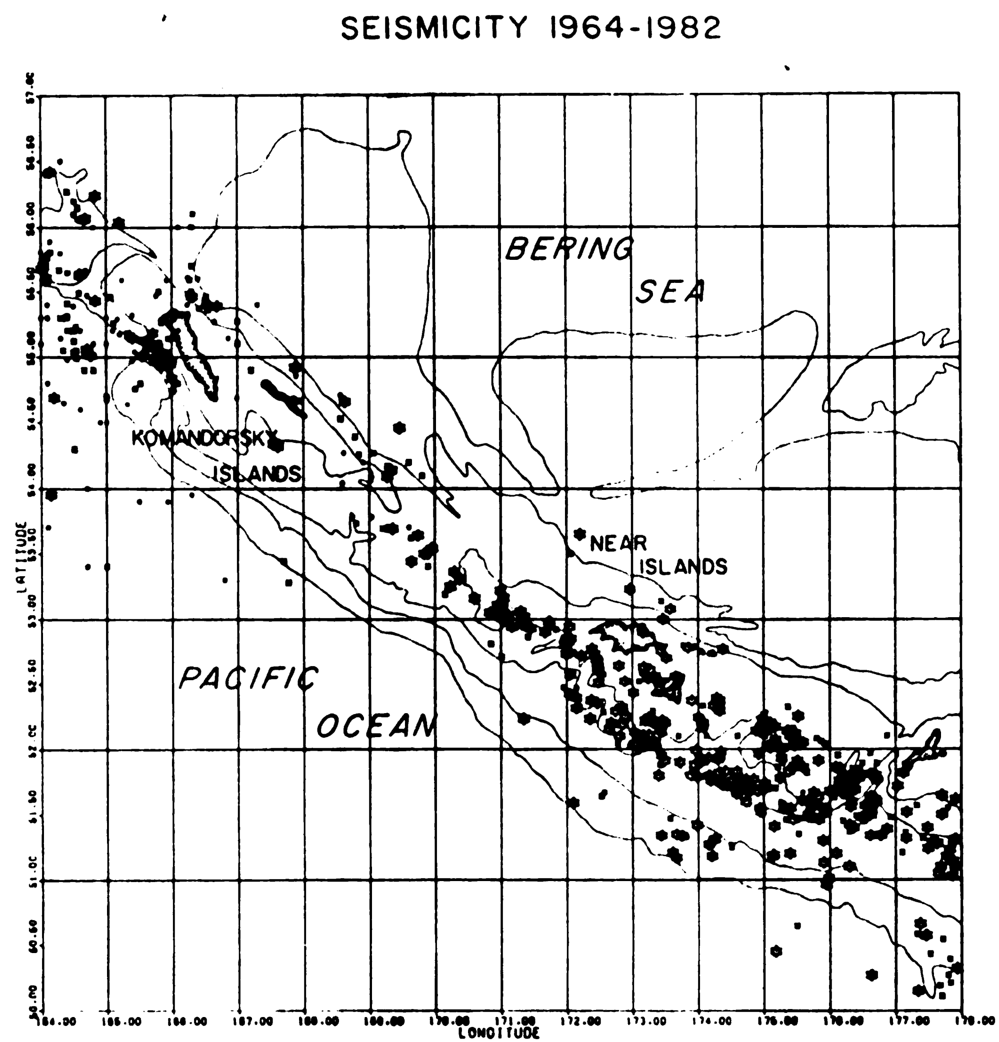


Figure 5-Seismicity of the Far Western Aleutians

single large event in the Komandorsky Islands in each of the years, which may account for the discrepency in the histograms. This correspondence is remarkable, considering that the annual average moment release is 3 to 5 times greater in the Near Islands region.

The spatial pattern of seismicity varies considerably in the study area (Figure 5). East of 170 degrees, there exist three easily distinguishable zones. A small number of events occur to the southwest of the bathymetric trench in a zone extending to about 172 degrees. Another, less easily recognized group occurs on the northeast side of the Aleutian Ridge, and is limited to the area from 172 degrees to about 174.5 degrees. The majority of epicenters in the Near Islands region occur in a broad, tapering zone which encompasses the trench and ridge area to around 169 degrees. Within this zone, an aseismic lineation occurs between 172 and 175 degrees which divides the zone into two groups each trending northwest. As will be noted in a later section, representative fault plane solutions from either side of this lineation appear to be very similar. The average ISC reported focal depth for the events within the central zone to the northeast of the lineation for the study period is 30.0 km, compared to 27.6 km for events south of this aseismic zone. In the zone to the southwest, 52% of the earthquakes considered in this study occured during February, 1965 as aftershocks of the Rat Island event of

February 4. Only 9% of the activity of the area northeast of the aseismic lineation occured during February, 1965; the bulk of the seismicity occuring later in 1965 and in subsequent years, so the quiet zone appears to seperate two groups of epicenters whose main difference is temporal.

In the Komandorsky Islands region, several zones of earthquake activity can be recognized (Figure 6). On the northeast side of the Aleutian Ridge, from 166 to 170 degrees, there occurs a sparce, northwest trending zone of epicenters. On the southern side of the ridge is a group of earthquakes which appear to be an extension of the main zone of epicenters in the Near Islands and extends to at least 168.5 degrees and may include the group of events located south of Ostrov Mednyy at 167.5 degrees. The densest cluster of earthquakes in the region occurs to the southwest of Ostrov Beringa, closely following the trend of the bathymetric trench. Between 164 and 165 degrees occurs a zone of epicenters that may be viewed as being somewhat aligned in a north-south fashion, particularly the events of larger magnitude. Another cluster of events occurs near 164 degrees at around 55.7 degrees latitude. These trends of seismic activity will be discussed in relation to representative fault plane solutions in the region in a later section.

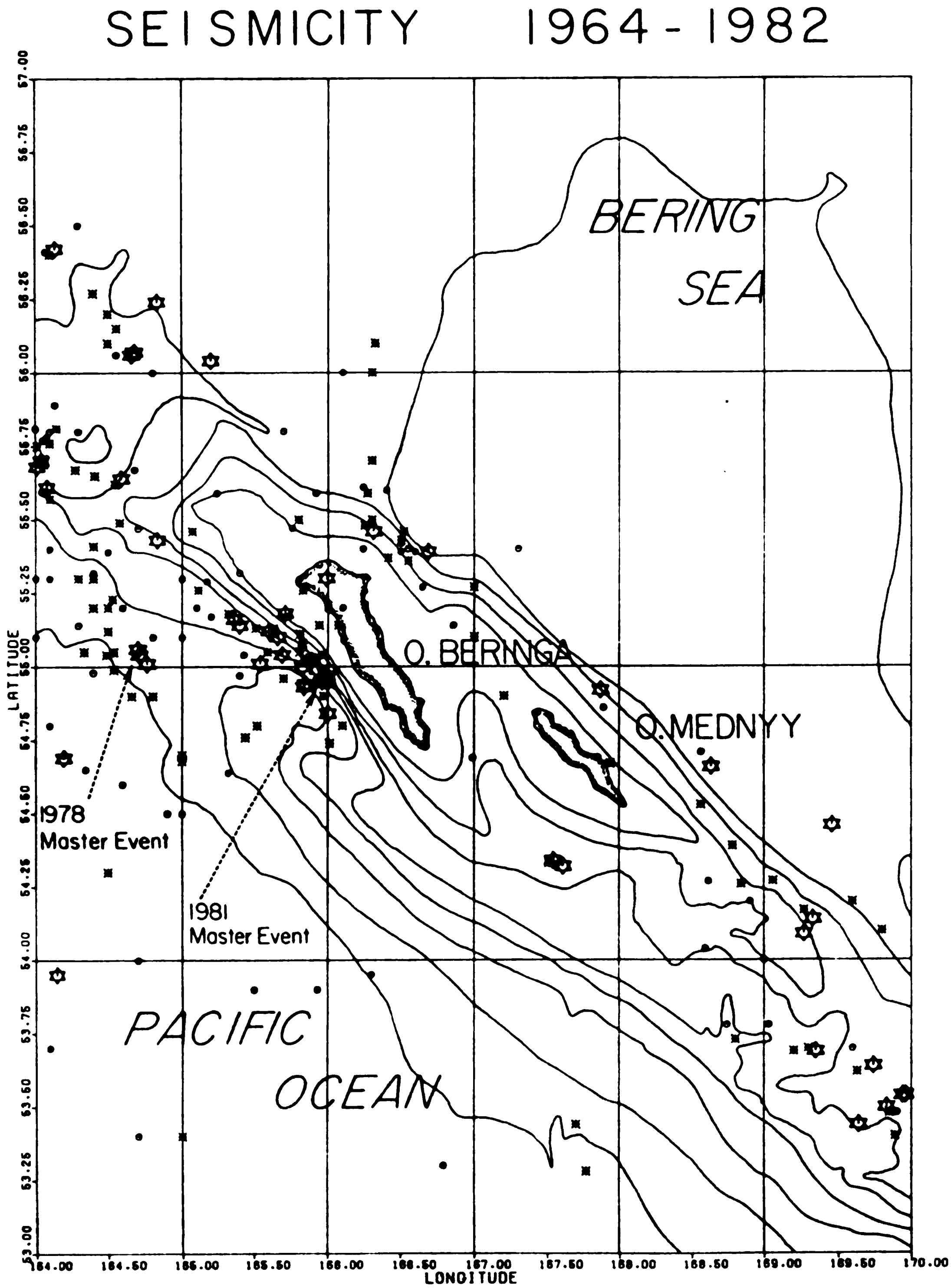


Figure 6-Seismicity of the Komandorsky Islands

Event Depths

The overwhelming majority of the events occuring in the Komandorsky Islands region have ISC reported depths shallower than 40 kilometers. Only 23 of the 211 earthquakes reported are 40 kilometers or deeper, only 6 of which are reported at depths of 80 kilometers or greater. Of the 393 events considered in the Near Islands region, 89 are reported to be at least 40 kilometers deep.

Since there are so few intermediate and deep events reported in the Komandorsky Islands, those that are may be considered suspicious. In order to more accurately constrain event depths in the region, synthetic seismograms were generated for three of the largest events in the region, two of which were reported to have occurred at greater than 40 km depth.

Since waveforms generated by earthquakes are sensitive to the relatively complex structure in and around island arcs, realistic layered models were assembled for each event. The compressional wave velocities, material densities and estimates of layer thicknesses were inferred from results of gravity and refraction work done on the Komandorsky Islands (Gaynanov et al., 1968) and other parts of the Aleutian arc (Stone, 1968; Shor, 1964; Murdock, 1969). Since the amplitude of the sP phase is small relative to the water surface reflection pwP for many types

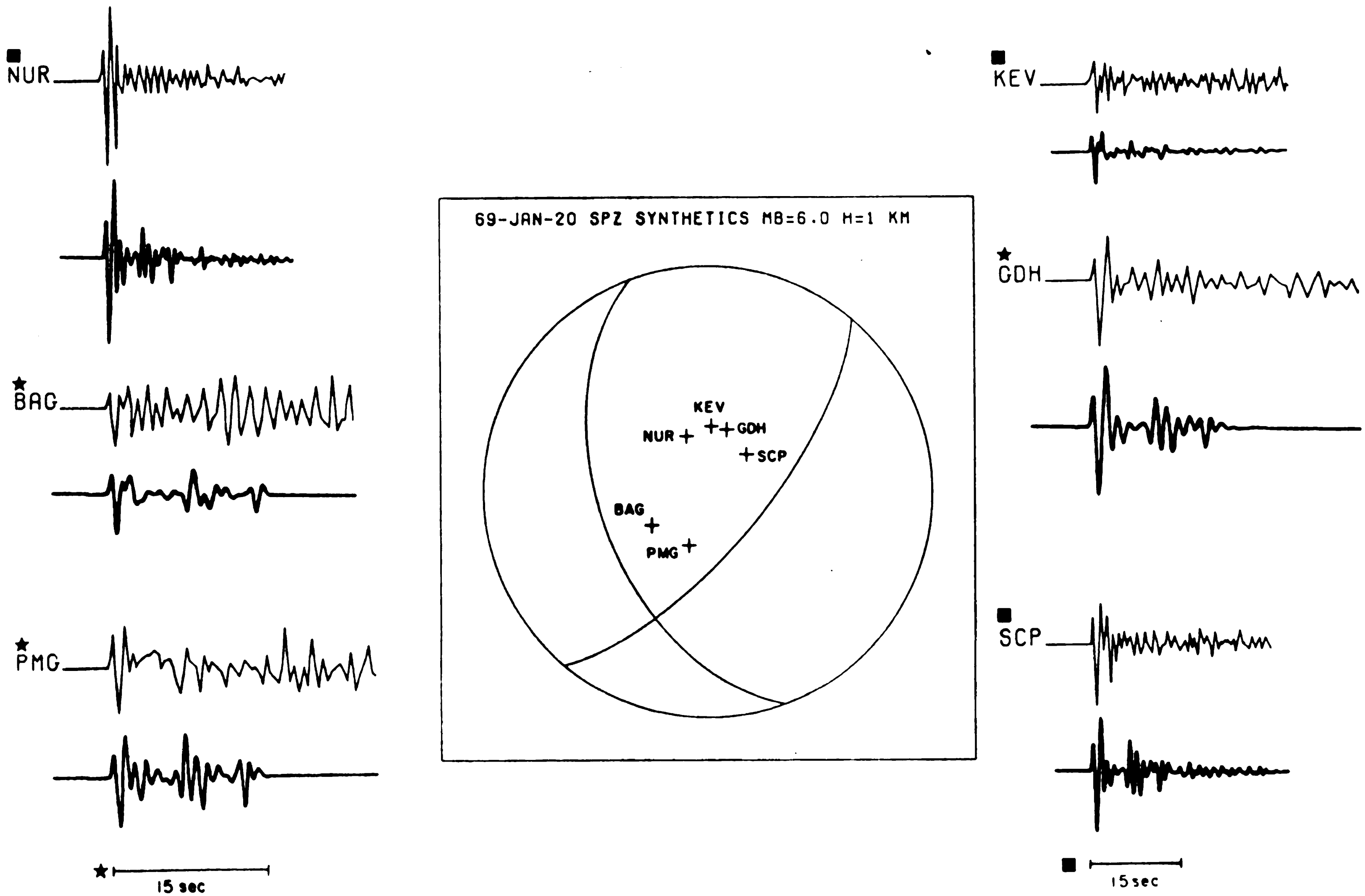


Figure 7:69-Jan-20 Synthetics

of submarine earthquake mechanisms (Hong and Fujita, 1981) rough estimates of the shear wave velocities were considered sufficient for the crustal models. Considering the uncertainty of crustal structure and that of comparing waveforms, the depths determined by generation of synthetic traces should be considered to be accurate to within 5 to 7 kilometers for shallow focus events (Hong and Fujita, 1981; Wiens and Stein, 1983), an accuracy much better than that achieved from consideration of teleseismic arrival times.

The event of January 20, 1969 has an ISC reported focal depth of 17 km and a magnitude of 6.0 (mb). This magnitude determination is questionable, since very little energy was noted on long period records. This may simply reflect a fast rupture, as indicated by the short triangular source-time function used (.25,0.,.25 sec) or may be the product of constructive interference between the P and pP phases in the first few seconds of the wavetrain. The event was modelled on the basis of six short period records (Figure 7) using the focal mechanism determined by Cormier (1975a) which resulted in a focal depth of 1 km. The apparent water depth in the vicinity of the epicenter is deeper for stations to the south, consistant with the local bathymetry (Figure 12). Even though only six short period stations were used, the azimuthal coverage is good and the results are consistant.

The earthquake of August 15, 1975 was modelled using a trapezoidal source-time function (1.,1.,1. sec) for nine long period records (Figure 8a-c), resulting in a recalculated depth around 13 km, as opposed to 41 km determined by the ISC using P wave data. The water layer was found to be 1.75 km, one to two km shallower than the bathymetry directly over the reported epicenter. Moving the epicenter a few kilometers southwest toward the Komandorsky Islands would satisfy this observation.

The largest event to occur in the area in the past 20 years (February 19,1977; mb=6.1) was modelled on the basis of 11 long period records using a simple velocity structure from Gaynanov et al. (1968) and a symmetric trapazoidal source-time function (2.,2.,2. sec). The depth this analysis yielded was 20 to 23 km (Figure 9a-f) with an estimated water depth of 2.2 km. The determination of the water depth was not as clear cut as was hoped, since it appears that the event may have been a complex rupture, complicating the later parts of the waveform. The original focal depth of 44 km was reportedly determined by the ISC on the basis of pP-P times. Since the water surface reflecton pwP is often very prominent. in oceanic thrust mechanism earthquakes (Hong and Fujita, 1981), it can be misidentified as pP resulting in a significant overestimation of focal depth, which is likely the case with this event.

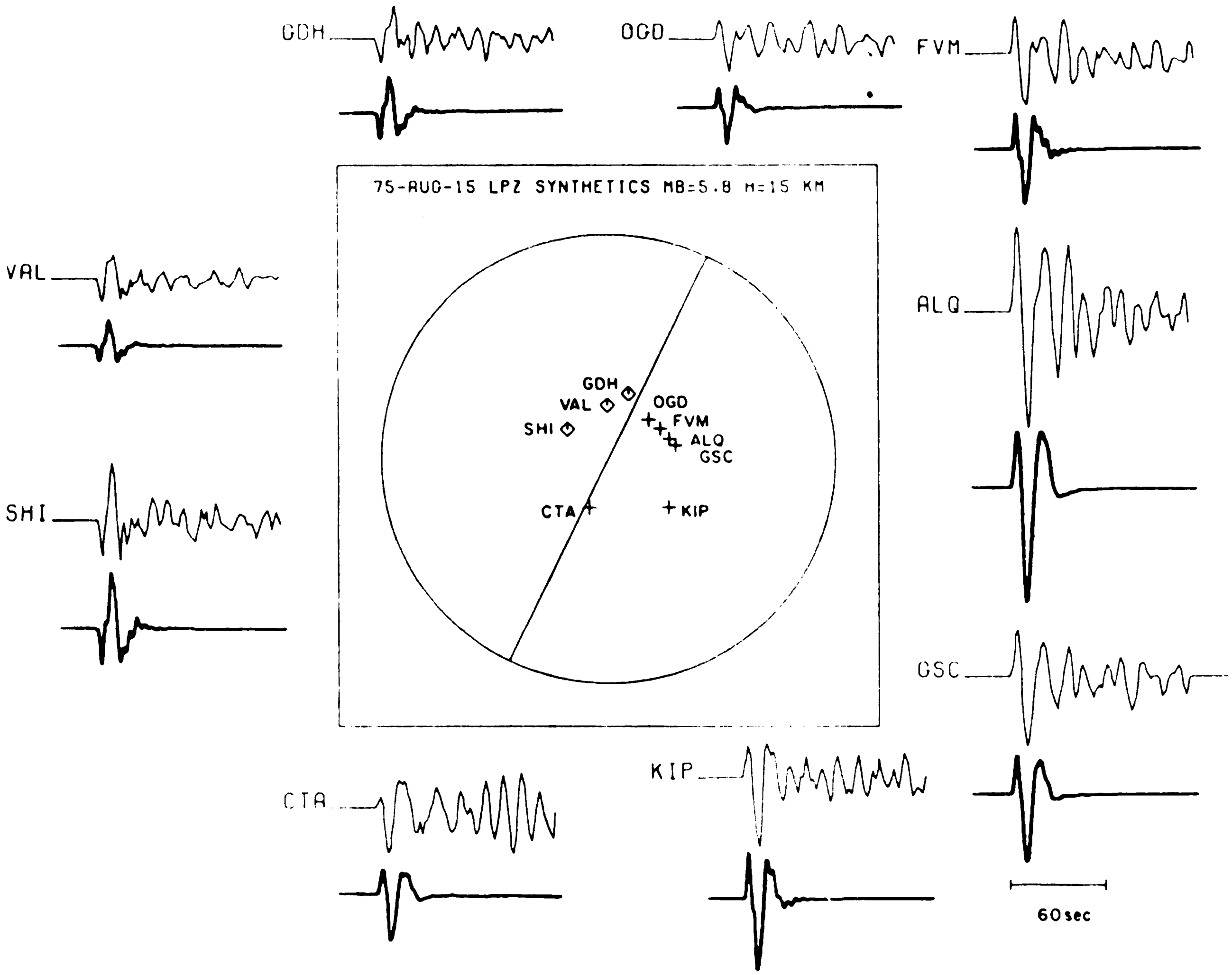


Figure 8a:75-Aug-15 Synthetics

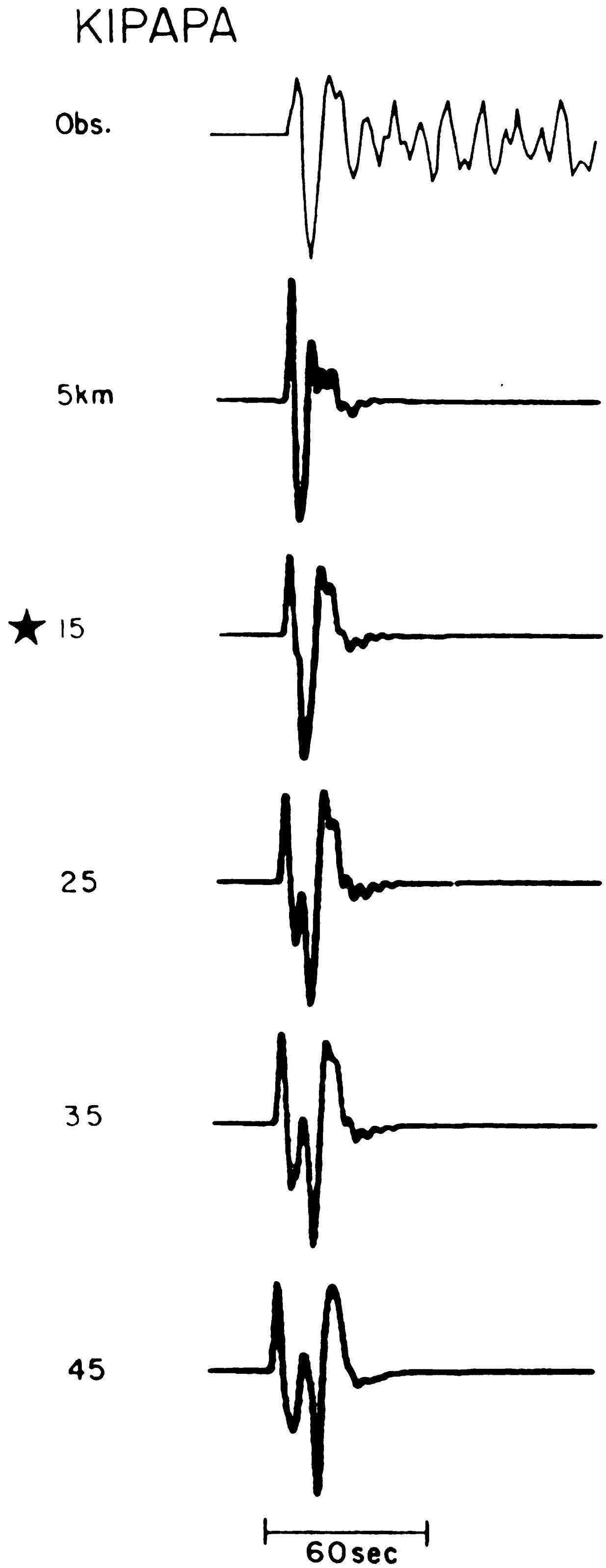


Figure 8b:75-Aug-15 Synthetic traces at several depths: KIP

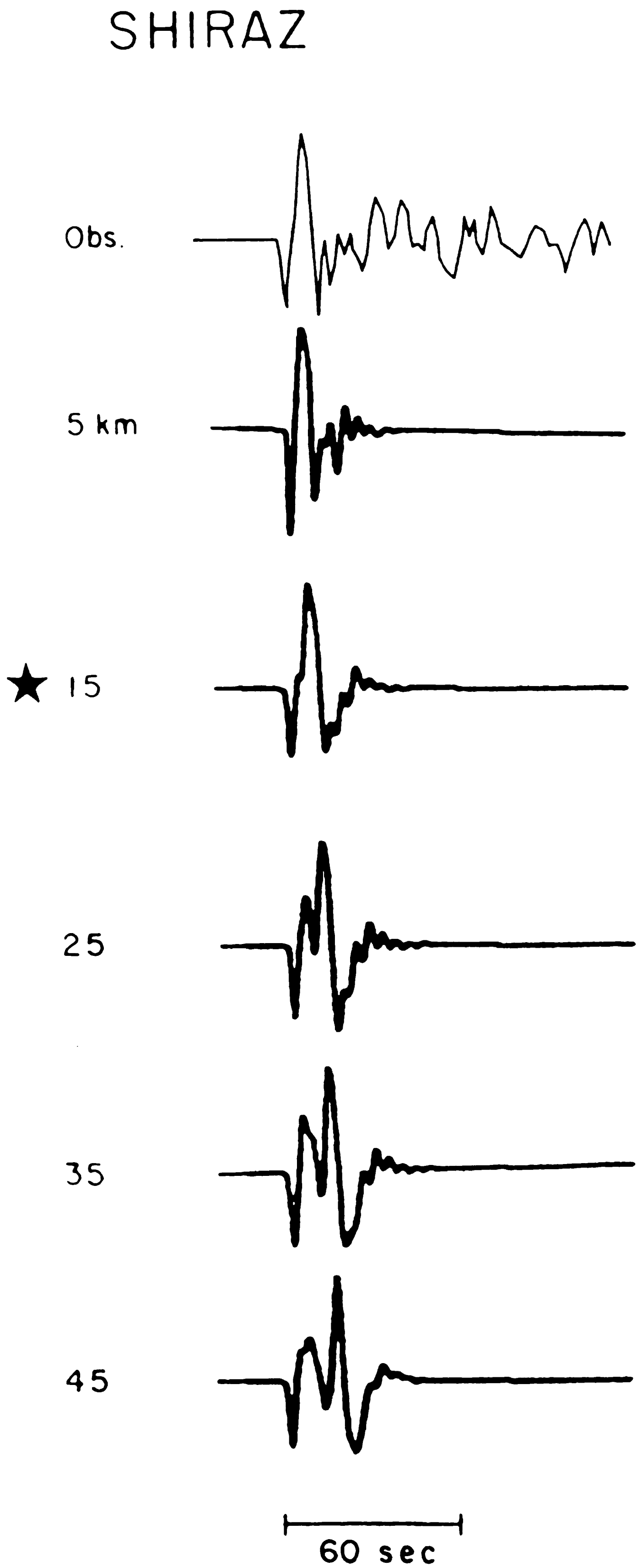


Figure 8c:75-Aug-15 Synthetics at several depths: SHI

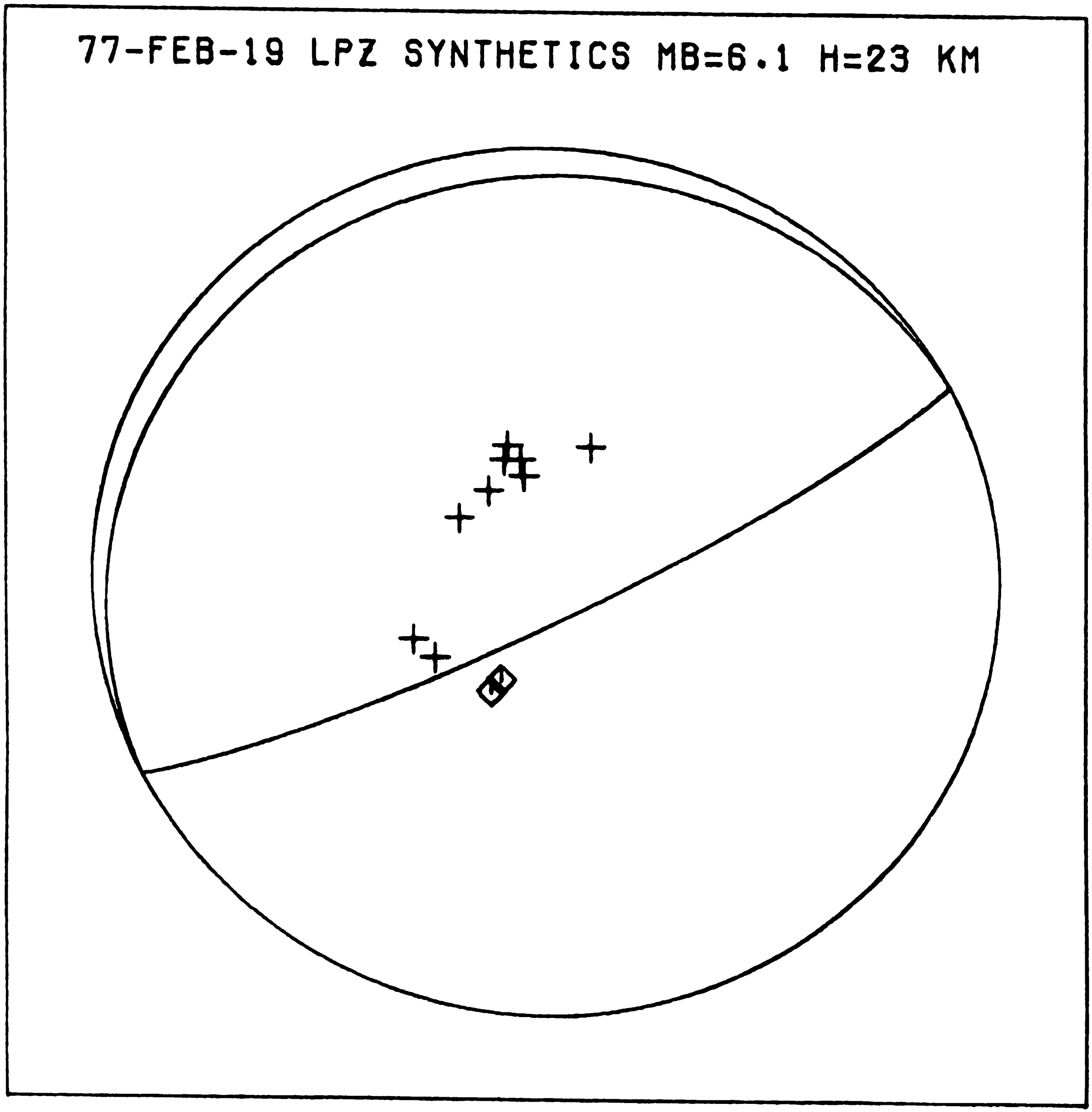


Figure 9: Synthetic seismograms for 77-Feb-19
a: Mechanism and stations
b-f: Synthetic traces (arranged by increasing azimuthal distance)

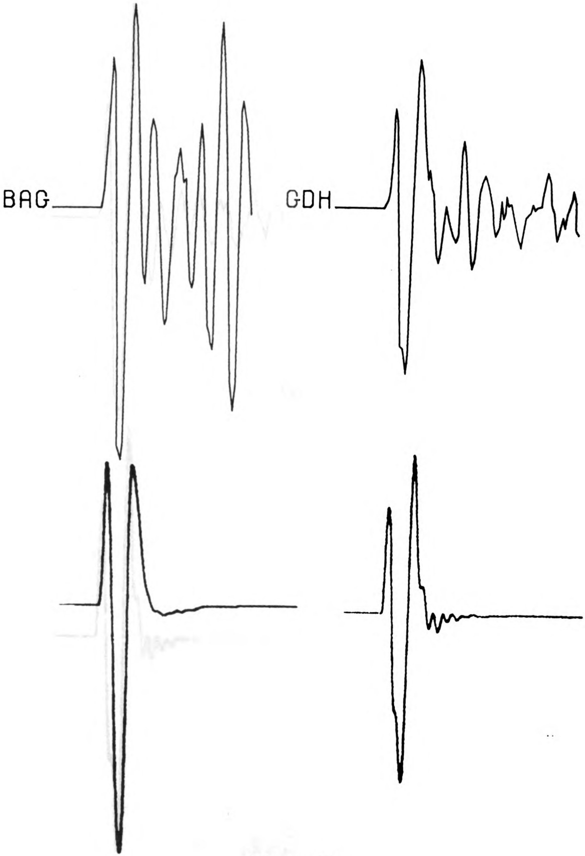


Figure 9b

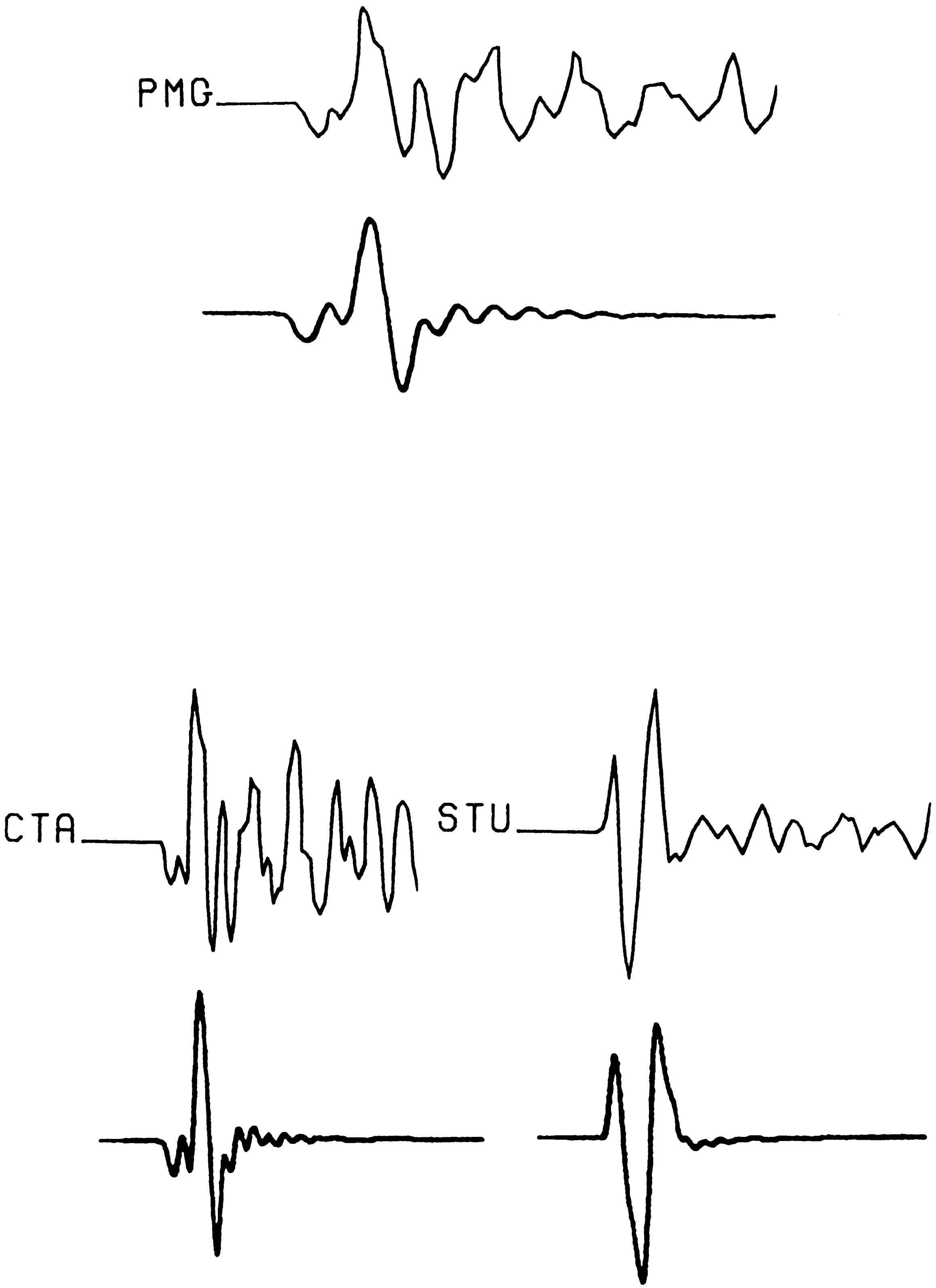


Figure 9e

Figure 9f

The earthquakes in the Komandorsky Islands with focal depths reported at 80 kilometers or greater are so few and small in magnitude (these deepest events all have magnitudes mb < 4.4), that using them to draw any conclusions about brittle rupture at these depths would be unfounded. The epicenters of several of these earthquakes are located seaward of the trench, which also tends to contradict the conclusion that these events are a result of rupture of subducted oceanic lithosphere at depth. Since these events are so small, no depth phases could be seen clearly on the available short period records, so verification of the depths was not possible.

Fault Plane Solutions

Fault plane solutions were determined for earthquakes in the region utilizing P-wave first motion data from the Bulletins of the ISC and USGS, and reading key stations whenever possible. Short period records provided the only useful information for all but the very largest events. Confidence on the restraint of focal planes is quite varied. Events for which mechanisms are presented are listed in Table 1 and focal mechanisms and data are given in Appendix C.

The mechanisms characterizing the eastern part of the study area, from 170 to 178 degrees east, are shown on

Table 1-Earthquakes for which mechanisms are presented

Mech	Event	Time	Lat	Long	Depth	Mag	Source
1	65-Oct-16	20 01	56.07	164.68	4	5.2	N
2	69-Apr-04	22 57	54.46	169.46	1	5.5	N
3	75-Jan-28	11 53	56.06	164.66	7	5.1	N
4	77-Apr-12	3 54	55.64	164.59	42	5.0	N
5	78-Mar-03	10 53	55.60	164.70	45	5.5	N
6	79-Sep-14	7 28	53.64	169.74	28	5.8	N
7	79-Nov-09	13 45	55.61	164.08	26	5.7	N
8	65-Jul-21	17 52	53.31	170.38	0	5.7	N
9	70-Apr-26	14 20	52.93	171.45	12	5.8	N
10	71-Jul-25	15 41	52.13	173.03	36	5.8	N
11	71-Nov-22	0 46	52.33	174.23	38	5.7	N
12	73-Mar-19	11 41	52.78	173.85	81	5.7	N
13	73-Mar-23	6 55	51.27	174.16	21	5.7	N
14	74-Aug-20	20 44	52.17	174.95	42	5.7	N
15	75-Feb-02	8 43	53.08	173.58	10	6.0	N
16	75-Feb-02	7 24	53.00	173.47	2	5.9	N
17	80-May-03	9 30	51.21	173.61	38	5.8	N
A	59-May-12	4 57	54.95	168.17	33	6.5	C
B	63-Aug-08	2 12	54.28	168.23	38	6.2	C
C	65-Feb-08	15 46	55.12	165.60	35	5.7	C
D	65-Sep-13	13 07	55.30	165.99	21	5.4	C
E	66-Jul-19	1 40	56.24	164.83	20	5.3	C
F	68-Jul-28	21 12	55.39	166.69	14	5.4	C
G	69-Jan-20	14 20	54.84	166.00	1*	6.0	C
H	69-Apr-17	12 48	55.27	167.00	9	4.9	Z
I	73-Nov-17	5 45	54.17	169.27	16	4.7	L
J	73-Dec-29	8 20	54.66	168.63	32	5.4	L
K	74-Feb-08	14 21	54.32	167.61	23	5.4	L
L	75-Aug-15	7 28	54.92	167.87	13*	5.8	L
M	75-Nov-04	12 05	54.34	167.54	15	5.4	L
N	77-Oct-09	4 06	54.74	166.01	42	4.8	L
O	78-Nov-17	5 33	54.09	169.27	9	5.1	L
P	82-May-31	10 21	55.14	165.40	33	6.0	U
Q	65-Feb-04	12 06	52.74	172.05	30	5.8	S
R	65-Feb-04	14 18	53.03	171.08	16	5.7	S
S	65-Feb-05	9 32	52.37	174.33	16	5.9	S
T	65-Feb-05	20 47	51.83	174.41	30	5.7	S
U	65-Feb-06	4 02	52.05	175.60	35	5.9	S
V	76-Feb-07	2 17	51.34	173.44	45	5.8	S
W	65-Mar-30	2 27	50.32	177.93	20	6.5	S
X	65-May-23	23 46	52.17	175.17	31	5.9	S
Y	66-Jun-02	3 27	51.01	175.98	48	5.7	S
Z	77-Feb-19	22 34	53.54	169.96	25*	6.1	L

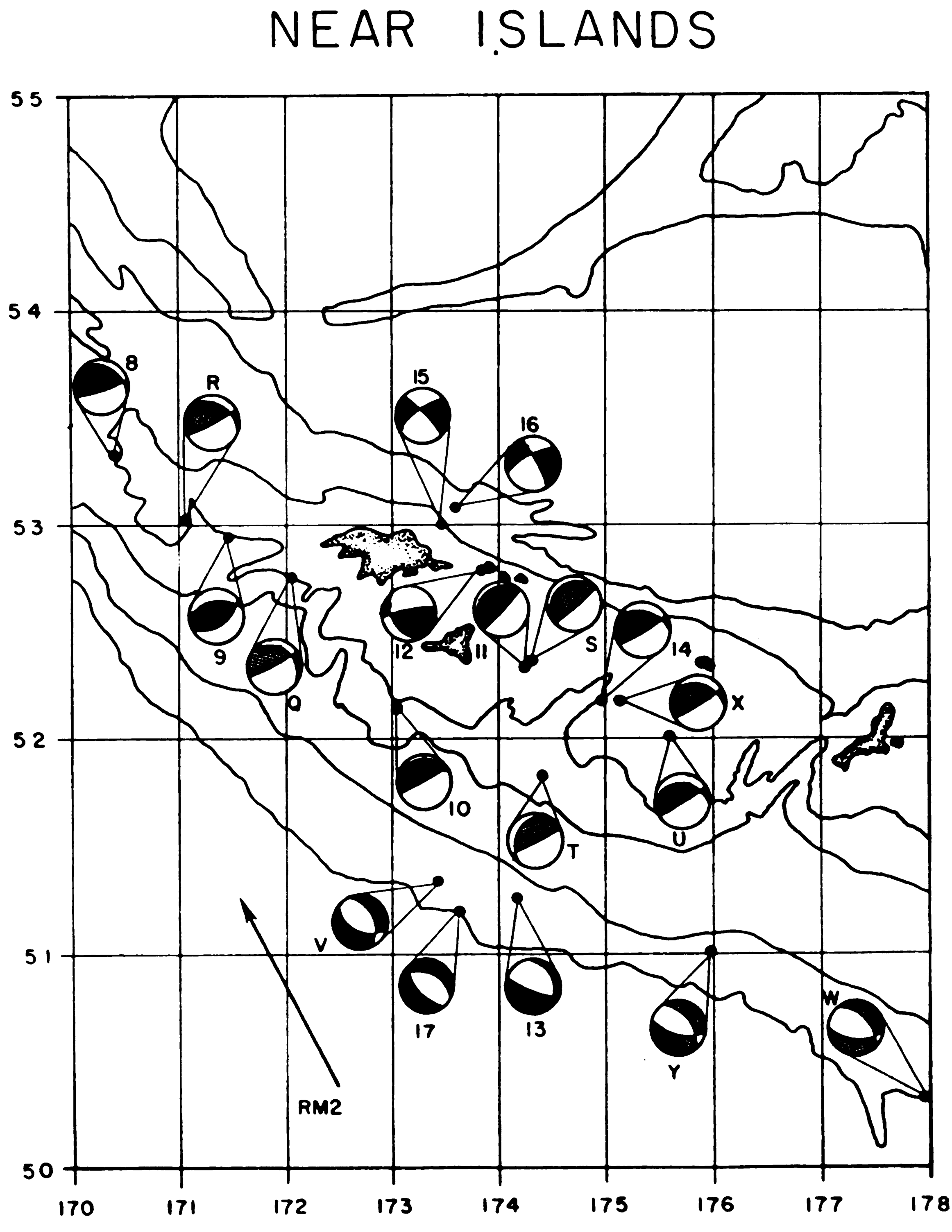


Figure 10 Near Islands mechanisms (solid: this study)

Figure 10. As was described by Stauder (1968), these solutions fall into two major groups: a zone of normal faulting mechanisms to the south of the ridge, in and around the bathymetric trench, and a zone of low angle thrust faulting located beneath the Aleutian ridge. Of the 19 mechanisms shown, all but three of the ten mechanisms determined in this study are concordant with these groupings. Note that representative mechanisms from either side of the northwest trending aseismic lineation in the central zone of seismicity are essentially identical. One of the solutions that fits neither catagory (Solution 12) was reported to occur at 81 kilometers depth and indicates a large component of normal faulting. The two remaining mechanisms constitute a strike slip doublet of events occurring on February 2, 1975. These mechanisms were interpreted as representing right lateral strike slip motion along a northwesterly fault plane (Cormier, 1975b), as an extension of strike slip faulting described by Cormier (1975a) in the Komandorsky Islands to the west. However, the choice of the northeast trending nodal plane as the fault plane can be justified by noting that Agattu Canyon to the south of Attu Island (Figure 11) and major faulting on Attu Island itself (Gates et al., 1971) are aligned quite well with the trend of this focal plane. Agattu Canyon has been interpreted as delineating the boundary between two tectonic blocks of the Aleutian Arc (Spence, 1977) at least

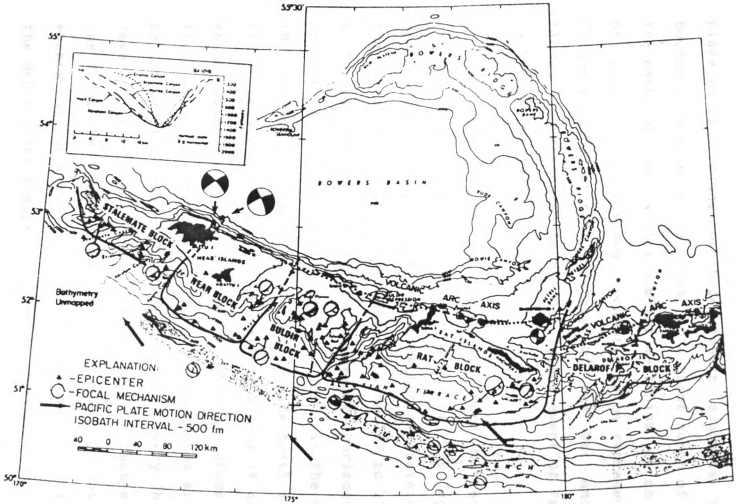


Figure 11-Aleutian tectonic blocks (from Spence, 1977)

as far north as the 100 meter bathymetric contour south of Attu Island (Figure 11). Choice of the northeast nodal plane as fault plane for these events suggests that this boundary may extend at least to a point north of Attu. To the east, an event with a similar mechanism which occurred on July 4, 1966 has been suggested to be representative of "ridge rebound" at the boundary of the Rat and Delarof blocks in response to the Rat Island event of February 4, 1965 (Spence, 1977).

The fault plane solutions are more varied and in general less well constrained west of 170 degrees, but spatial consistancy is observed. Mechanisms determined for the area south of Ostrov Mednyy from 167 to 170 degrees east imply thrust faulting on a nearly horizontal plane (Figure 12). The largest event to occur in the area (Feb. 19, 1977, mb=6.1) is of this type. On the north side of the ridge between 167 and 170 degrees is a zone of earthquakes which appear to have mechanisms opposite to those just to the south. If the nearly vertical focal planes are taken to be the fault planes, the mechanisms imply very high angle reverse (or normal) faulting, with the southeastern side of the fault downdropped with respect to the northwest. These events are generally reported to be comparatively deep, but the depth phase analysis of one such event (August 15, 1975, mb=5.8) introduces significant doubt in to this interpretation. The area surrounding Ostrov Beringa is

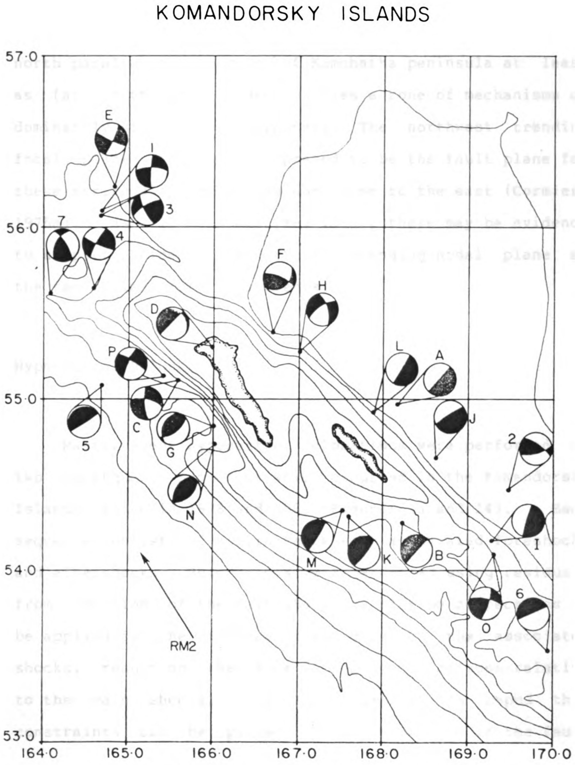
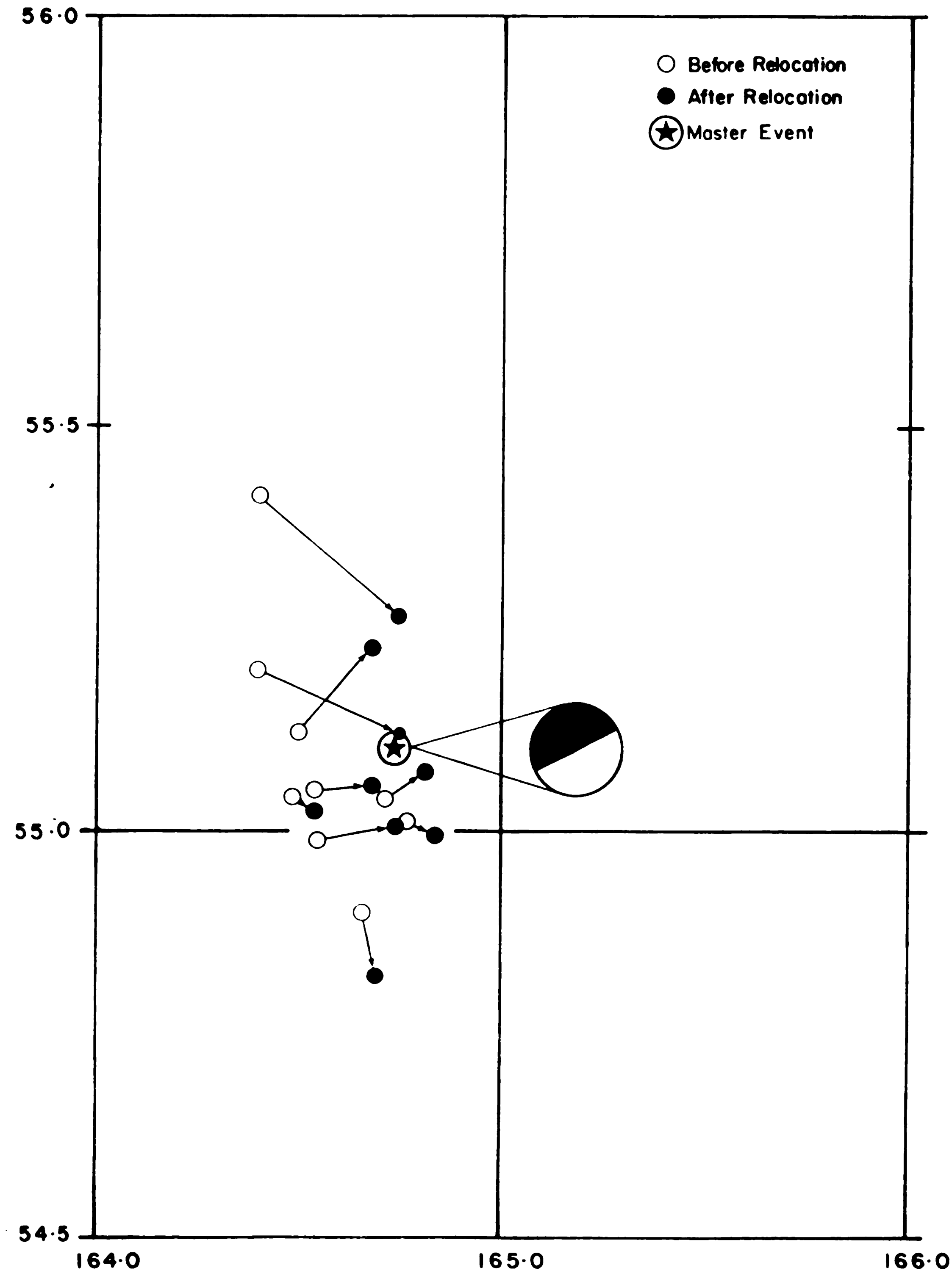


Figure 12-Komandorsky Mechanisms (light shaded: Cormier, 1975a)

characterized by both strike slip and reverse faulting mechanisms. To the west of Ostrov Beringa and extending north parallel to the coast of Kamchatka peninsula at least as far north as 56.5 degrees lies a zone of mechanisms of dominantly strike slip character. The northwest trending focal plane has been interpreted to be the fault plane for these strike slip mechanisms and those to the east (Cormier, 1975a). As will be summarized later, there may be evidence to support choice of the northeast trending nodal plane as the fault plane for these events.

Hypocentral Relocations

Master event hypocentral relocations were performed on two earthquake sequences which occurred in the Komandorsky Islands region in 1978 and 1981 (Figures 13 and 14). Each sequence consists of a main shock with associated foreshocks and aftershocks. Relocations were performed using residuals from location of the main shocks as station corrections to be applied to the arrival time data of the associated shocks, resulting therefore in improved locations relative to the main shocks. In this way, it is hoped that constraints can be placed on the direction of the fault planes on which these events occurred.



RESULTS OF RELOCATION OF 1978 SEQUENCE

Figure 13

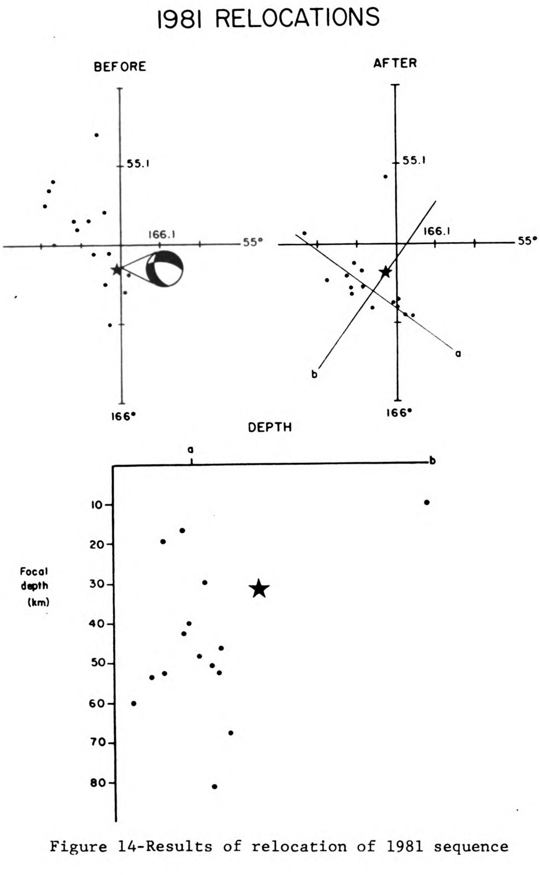


Figure 14-Results of relocation of 1981 sequence

The sequence of events occurring on February 9-10, 1981 consists of 4 foreshocks, the master event, and 11 relocatable aftershocks. The mechanism for the master event has been determined using both first motion data and surface wave analysis (D. L. LaClair, pers. comm.). The relocated hypocenters appear to delineate a nearly vertical, northwest striking fault plane (Figure 13) which does not appear to closely resemble either nodal plane of the mechanism of the master event. However, since the hypocenter of the master event falls to the northeast of the projection of the main cluster of events, the possibility exists that this earthquake stimulated rupture of a seperate fault slightly to the south. Only one of the relocated earthquakes was considered to be unreliable, and therefore was not included in the plot of the relocations.

The sequence of March through December of 1978 consisted of four foreshocks, the master event, and five aftershocks that could be confidently relocated. As can be seen in Figure 14, the events which originally defined a somewhat northwesterly trend tend to cluster on a more northerly plane as a result of relocation. This may be taken to indicate this sequence ruptured a roughly northerly trending plane.

DISCUSSION OF RESULTS

The study of the seismic activity of the far western Aleutians during the past 19 years has lead to several interesting results. Although the level of seismic activity diminishes abruptly between the Near Islands and the Komandorsky Islands, it has been shown that the temporal moment release characteristics are quite consistant. The geologic evidence implies no major structural boundary between the Near and Komandorsky Islands regions. These observations lead to questions regarding the maturity of the Komandorsky Islands seismic gap. The consistancy noted in Figure 4 indicates that either stress is accumulating in the region at a rate linearly related to the annual moment release, or more likely is being accomodated aseismically. If the latter case is correct, then the Komandorsky Islands region is no more likely to experience a great earthquake than any other section of the arc.

The study of two event depths using body wave synthetic seismograms yielded results that differed significantly from the focal depths determined by consideration of p-wave arrival time data by the ISC. Since the synthetics indicated consistantly shallower depths, it may be concluded that some sort of seismic velocity anomaly is indicated in the source region. This anomaly may reflect the effects of a remnant lithospheric slab at the source, or may simply be a result of bias in the travel time tables used in the location procedure resulting in an apparent velocity anomaly. The focal depth of the third earthquake modelled with synthetic seismogram analysis was likely overestimated as a result of the misidentification of depth phases.

The zones of similar tectonic activity as inferred by the study of fault plane solutions in the far western Aleutians are presented in Figure 15. In the eastern section of the area, a zone of normal faulting is indicated which likely is a result of tensional stresses arising from bending of the lithosphere seaward of the site of subduction at the Aleutian trench. This zone, and likely this stress regime, ends near 172 degrees.

To the north of Attu Island in the Near Islands, the occurance of a doublet of strike slip earthquakes may be taken as indication that the boundary between the Stalemate and Near tectonic blocks of Spence (1977) extends north of where it had been previously described. The other mechanism in this area, which is dominantly of normal faulting character, is reported to occur at 81 kilometers depth (it may be shallower, as has been shown for other events in this study), and may be a result of tensional stresses in the subducted lithospheric slab beneath the Near Islands.

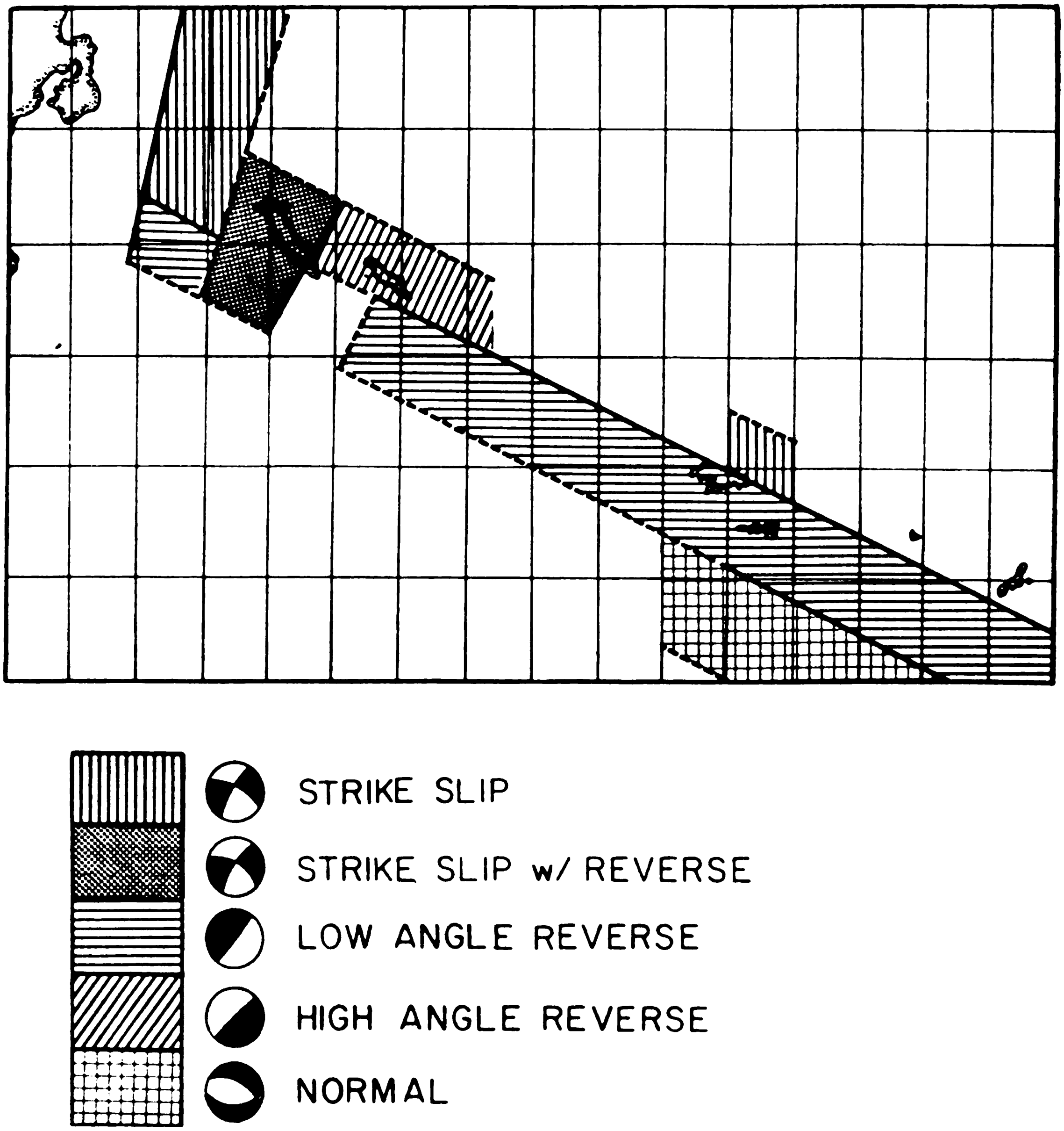


Figure 15-Zones of like focal mechanisms

The zone of low angle reverse faulting which encompasses the Aleutian trench and ridge extends from the Near Islands to 169 degrees and possibly to around 167 degrees. The mechanisms of this zone indicate that thrusting on nearly horizontal planes takes place south of the Aleutian Ridge at least as far west as Ostrov Mednyy. This may be taken to indicate that either active underthrusting of the Pacific plate is occurring in this section of the Aleutian trench or that the strike slip relative motion between the two plates is occurring on a horizontal fault plane. Since normal faulting mechanisms occur only as far west as 172 degrees and active volcanism is absent west of Kiska Island, vigorous underthrusting seems not to be occuring in the Komandorsky Islands.

The area around Ostrov Mednyy is dominated by the occurance of dip slip faulting on vertical planes, although one strike-slip mechanism was found for this area. Cormier (1975a) noted one of these high angle reverse faulting mechanisms in his study and suggested that it may have been mislocated toward the Aleutian Ridge and actually reflected tectonism in the Komandorsky Basin to the north, not directly related to ridge processes. This study has identified several additional events with similar focal mechanisms, one of which (August 15, 1975) was modelled by synthetic seismogram analysis, yielding a water depth more characteristic of the ridge area than the oceanic basin to the north. These focal mechanisms are not aligned along the strike a single vertical focal plane, and therefore are interpreted as representing at least three seperate occurances of dip slip faulting, each indicating a downthrown southeastern block. Gravity modelling of the Komandorsky Islands and the western Bering Sea by Gaynanov et al. (1968) suggests a long narrow block (extending to 70 km depth) of material of reduced density under the western Aleutian Ridge. If this interpretation is accurate, it may be indicative of a remnant of subducted oceanic crust. The contrast of densities between this slab and the surrounding material could produce bouyant forces, causing the vertical movements suggested by the fault plane solutions.

West of 167 degrees, mechanisms of dominantly strike-slip character appear. In the zone surrounding Ostrov Beringa, reverse faulting occurs with strike-slip faulting but the mechanisms determined do not allow the identification of specific fault trends. Cormier (1975a) chose the northwest trending focal planes as the fault planes for the strike-slip mechanisms in the Komandorsky Islands, the plane and sense of motion being most consistant with the relative motion vector in this area. This choice appears to be appropriate for the events occuring in the bathymetric trench south of Ostrov Beringa, considering the results of relocation of the 1981 sequence and the general local alignment of epicenters. For the mechanisms between

164 and 165 degrees, there are several indications that choice of the northeast trending plane may be justified. The seismicity west of Ostrov Beringa tends to be aligned roughly north-south, especially the larger events, and extends at least to 56.5 degrees north. The bathymetry of the area (Figure 6) indicates a northward trending trough in the area of some of the mechanisms northwest of Ostrov Beringa. If the northeast trending focal planes are chosen as representing the plane of strike slip faulting in the area, then a northerly component of the stress field in the area is causing some (localized?) northward movement of the western Aleutian Ridge with respect to Kamchatka. The results of the relocation of the 1978 earthquake sequence indicate clustering of the epicenters along a more north striking plane, implying that the thrusting noted southwest of Ostrov Beringa is a continuation of the strike slip zone to the north (Model A, Figure 16). If the northwest striking planes are chosen to represent the fault planes in the area (Model B, Figure 16), then a series of enechelon faults is envisioned, which extends to at least 56 degrees north, some 100 kilometers north of the apparent plate boundary at the trench. The simplicity of the first scheme, requiring only one fault plane instead of a wide diffuse zone of faulting, lends support to the choice of Model A as the most plausible.

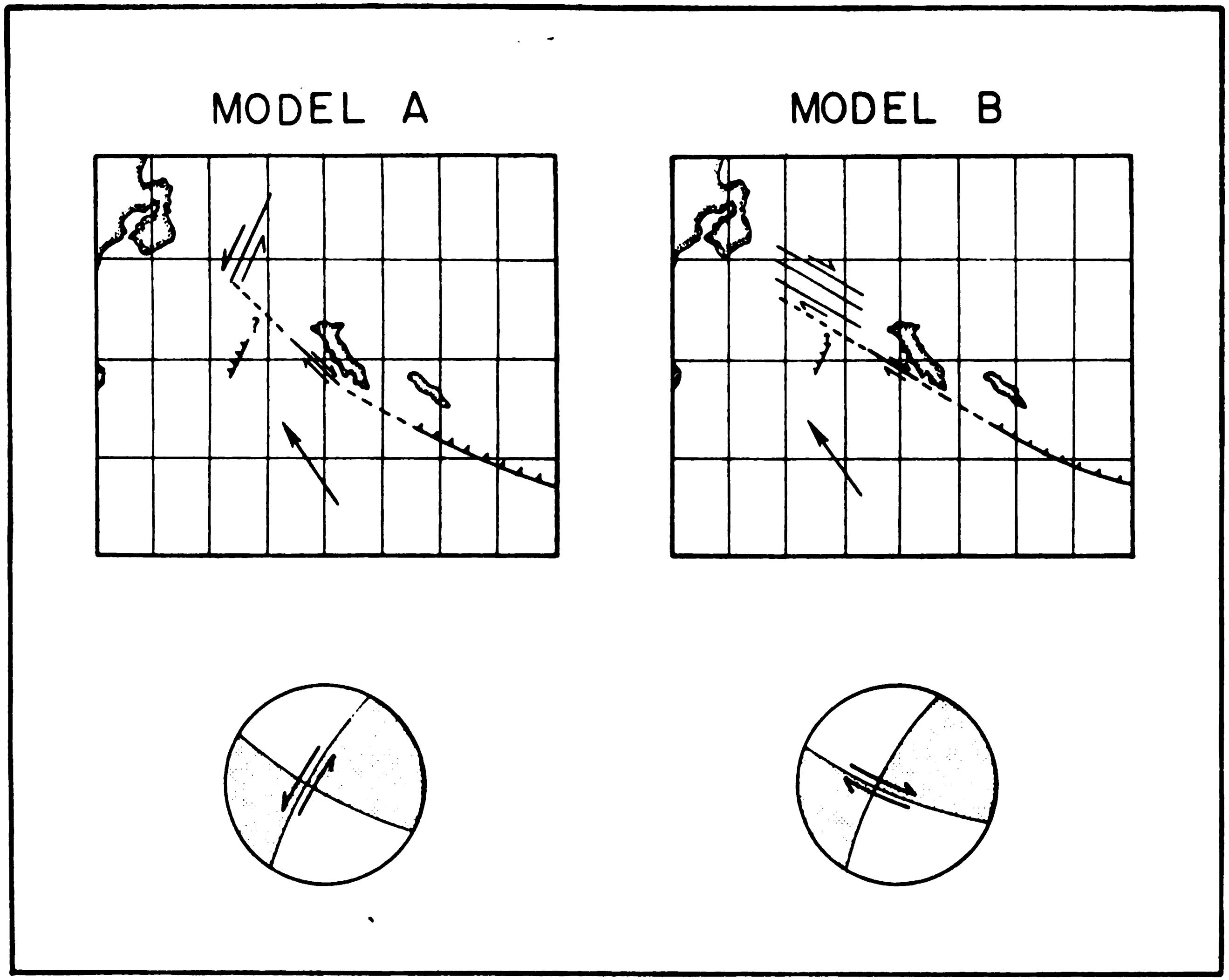


Figure 16-Models for faulting in the Komandorsky Islands

CONCLUSIONS

This study has shown that the far western Aleutian Islands have likely been part of a continuous Aleutian arc since its formation in early Tertiary and that no major structural boundary seems to exist to account for differences in the seismicity of the Near Islands and the adjacent Komandorsky Islands region, therefore introducing doubt as to the existance of a true seismic gap in the area.

It has also been shown that the tectonics of the far western Aleutian arc can not be simply described by large scale right lateral strike slip faulting. Northwest trending strike slip faulting may only occur in a limited zone to the south of Ostrov Beringa. Thrusting and vertical movements have been found to be significant manifestations of strain in the region and left lateral relative motion between the western Aleutian Ridge and Kamchatka Peninsula has been postulated. The most recent model of modern plate motions (RM2 of Minster and Jordan, 1978, shown on Figure 12) indicates a relative motion vector between the North America plate and the Pacific plate which contains a small component of convergence between the two plates even as far west as the Komandorsky Islands. This component may be sufficient to account for the thrusting and lack of extensive strike slip faulting east of 166 degrees, and may give rise to some of the northward movement of the Aleutian Ridge. Another possible explanation for north-south strike slip faulting in the west involves the consideration of possible southward movement, or clockwise rotation of the proposed Okhotsk plate which may contain the Okhotsk Sea and Kamchatka Peninsula (Chapman and Solomon, 1976). Recent work of Stone et al. (1982) in southern Alaska and the eastern Aleutians has indicated that the Bering Sea and the Aleutian Ridge have been moving northward throughout the Cenozoic. The movement postulated by this study in the west may possibly be an indication that the whole of the Aleutian arc is moving northward today.

APPENDICES

APPENDIX A

Geology of the Komandorsky Islands

The Komandorsky Islands consist mainly of volcanic rocks and volcanogenic sediments. The Soviet field geologists have described the assemblege in terms of six suites of rocks, the lower four of which constitute the Komandorsky Series (Schmidt, 1978). The entire stratigraphic sequence reflects a transition from basaltic submarine volcanism to subaerial extrusion of andesitic and dacitic magmas. Each component of the stratigraphic sequence is commented upon below.

The Komandorsky Series

The Preobrazhenskoye Suite

This lowermost suite of the Komandorsky Series contains the oldest rocks found to outcrop on the Komandorsky Islands. The suite consists of contrasting effusives (define), basaltic pillow lavas, and pelitic and psammitic tuffs. These rocks grade from small pillows of porphyritic basalt (containing augite, hypersthene, and basic plagioclase) to larger basaltic pillows with coarse autoclastic breccias and basic tuffs. Massive lavas with crude columner jointing are found and the upper parts of the suite grade in to lighter colored basalts and tuff sandstone and tuff spilites. The suite is estimated to be at least 600 meters thick.

The Gavan' Suite

This suite of rocks contains lava breccias, tuff-spilites, pelitic and psammitic tuffs and tuff sandstones and conglomerates. The Gavan' Suite is characterized by the absence of pillow lava flows, although some fragments of pillows are found. Pyroclastics and some concretions appear in the upper parts of the suite which is reported to be about 900 meters thick.

The Gavrilov Suite

This suite of rocks is described as containing pelitic and psammitic tuffs, light gray concretions of tuff-calcite, calcite horizons, tuff-conglomerates and tuff-sandstones, and lava breccias. All but the very top of this suite is composed of the pelitic and psammitic tuffs. The upper part is marked by the appearence of bands of tuff-breccias, tuff-sandstones and tuff-conglomerates which are suggested to indicate a transition to the overlying Poludennaya suite. The thickness of this suite is around 600 meters.

The Poludennaya Suite

This uppermost unit of the Komandorsky Series is composed of rhythmically interbedded tuff-conglomerates, tuff-gravellites, and tuff-sandstones. Large amounts of plant detritus and some coal appear anong with signs of wave action which are taken to indicate a shallow water environment with proximity to land. This suite is thought to be 500 to 700 meters thick.

The units of the Komandorsky Series are distinguished on lithologic bases, since each appears to lie conformably upon the preceding unit (except at the base of the lowermost Preobrazhenskoye Suite, where contact is unknown). The age of this lowermost suite has been determined to be Paleocene based on the occurence of tricamerate globigerinas, reported to be similar to the species *Globigerina nana* Chalilov, and *Globigerina* cf. *G. pseudobulloides* Plummer (Schmidt, 1978). The fauna in the middle and upper parts of the series are poorly preserved so the age has noit been well-determined, but by analogy to other suites in Japan and California, it is estimated that these upper units may be lower Paleogene, probably Eocene (Schmidt, 1978).

The Nikol'skoye Suite

The Nikol'skoye Suite lies unconformably over the rocks of the Komandorsky Series and is composed of alkaline andesites and basalts, stratified tuffites, diatomaceous tuffites, and tuff-conglomerates and sandstones. This suite is characterized by the appearance of shield volcanics. The extrusive rocks are found to grade from alkali basalts to andesites. Coalified detritus and fragments of tree trunks are common. The occurance of the minerals titanomagnetite, pyroxene, pigeonite, alkali hornblende (barkevikite), and dolomite is an assemblege of minerals unique to this suite. The titanomagnetite content in some of the lavas may reach 10-15 percent (Schmidt, 1978). The Nikol-skoye Suite has been dated at late Oligocene to early Miocene.

The Vodopad Suite

The Vodopad Suite consists of tuff-conglomerates and breccias, dacites, tholeitic basalts, and subaerial andesites. This suite is characterized by discrete, deeply eroded relicts of subaerial stratovolcanos, which appear as terrestrial lava flows of basalts, andesites, and dacites, and mud flows. Also noted are ignimbrite-like formations, and the floral remains of forests.

The Vodopad Suite lies unconformbly on the highly disected paleorelief of the Nikol'skoye Suite and Komandorsky Series below, and reaches a thickness of around 500 meters. Paleontological data are scarce within this suite, but it has been suggested that an age of Pliocene may be assigned (Schmidt, 1978).

APPENDIX B

Data Analysis Techniques

This appendix outlines the techniques used in the analyses of this study. Earthquake relocation, the determination of focal mechanisms and body wave analysis by the generation of synthetic seismograms will be discussed with regard to the assumptions and approximations involved in each technique and the validity of the conclusions drawn from their use.

Earthquake Relocation

Single event and master event relocations were performed using an iterative, least squares algorithm implimented by Hiroo Kanamori in a computer program known locally as "HYP2DT". Due to the execution time, precision, and core memory requirements of the FORTRAN coded program, the MSU Cyber 750 mainframe computer was used for all calculations.

The program accepts as input data the station code, P-wave arrival times for all stations (with epicentral distance < 100 degrees) reporting the earthquake to be located, and hypocentral estimates from which it calculates a theoretical P-wave arrival time to compare with the observed time for each station. The difference between the theoretical and observed times (station residuals) are then minimized by a least squares process by allowing the hypocenter and origin time to vary. The latitude and longitude are the major factors in determining this minimum with the event focal depth and origin time being of subordinate influence. In this regard, the formal precision with which the origin time and focal depth are often presented should not be confused with absolute accuracy. The travel time tables used to generate the theoretical arrival times (Jeffreys and Bullen, 1940) are empirically determined from enormous amounts of data collected at points all over the globe, they result in theoretical calculations reflecting a symmetrical earth and "average" crustal models. Since island arcs are by their very nature abnormal in structure, biases can be introduced in the location process. This bias may in part account for the apparent greater focal depths determined by this type of algorithm for the events upon which body wave analysis was performed.

Since the hypocentral estimates given by the ISC are generated by the above procedure, "relocation" of a single event must involve differences in assumptions to yield any further information. There are a couple of assumptions which can prove useful in this regard. One is to assume knowledge of one or more of the source parameters and disallow the program to change it. The event parameter most often chosen for this is the focal depth, often obtainable from analysis of body waves. Since focal depth and origin time are not highly influential parameters in the minimization, fixing one likely acts to vary the other much more than it affects the epicentral estimates. Another method of obtaining different results involves differences in the consideration of high residual stations. The ISC locations include high residual stations in their data set, although their effects are diminished by the use of weighting factors. Since modern recording, timing, and measuring equipment allow the determination of arrival times on short period records to within .3 seconds, residuals of greater than a few seconds may be considered suspicious. Inhomogenieties in the earth and slab effects can cause such high residuals, but can often be identified on the basis of consistancy of stations in a given direction or area. The assumption that is helpful in the relocation of events is that isolated high residuals are a result of misidentification of incoming phases, and are therefore esentially removed from the data set, hopefully resulting in more accurate hypocentral locations.

The program also allows for relative relocation of a master event and foreshock and aftershock (or master event and neighboring events) by assuming that the residuals calculated for the master event (usually the largest magnitude event in the area) are a result of inhomogeneites in the earth between the earthquake and its recievers and therefore may be applied as station corrections for other events located near the master event. The validity of this assumption may only be relied upon within a few hundred kilometers of the master event (Fujita, Engdahl, and Sleep, 1981). The result is that when these station corrections are applied to the subordinate events, precise locations, relative to the master event, will be obtained. This is commonly used to determine the direction of the fault plane involved in an earthquake using the pattern of its foreshocks and aftershocks thereby resolving the inherent ambiguity of a double couple focal mechanism. Since the largest shock in an area is usually considered to be the most accurately located by the standard technique, the relocations may not only be precise in a relative sense, but also more accurate in an absolute sense.

Fault Plane Solutions

Fault plane solutions were determined for earthquakes in the study area by using two standard techniques. The representation most heavily relied upon is that of presenting compressional wave polarizations on an azimuth versus focal angle of incidence plot on an equal area sterographic projection. The angle of incidence at the

focus (or take off angle) has been calculated for different values of epicentral distance (delta) and for different focal depths by Pho and Behe (1972). Each point plotted represents the point of emergence of a ray from the a sphere around the focus of the earthquake in lower hemisphere Schmidt net projection. It is then attempted to delineate zones of compressional and dilatational first motions (p-wave polarizations) by the projections of two orthogonal planes, representating the particle motion at the source due to a double couple faulting mechanism. The symmetry involved in the determination makes the distinction between the fault plane and the auxillary plane impossible to make. One must call upon other evidence to make this choice. Three primary sources of error are involved with plotting first motion data. The take off angle is highly dependant on the focal depth of the earthquake, which is often not well constrained. Errors of focal depth are often manifested in the inablilty to make the nodal planes meet the condition of orthogonality. Another source of error is the lack of complete azimuthal coverage and lack of close stations reporting first motions. In the case of western Aleutian earthquakes, the southeast quadrant of the focal sphere (representing the open Pacific Ocean) is nearly void of data, and reports of stations close to the source region are very scarce. The third major source of error results from misidentification or misreporting of the first motion by station operators and the ISC. To minimize this problem, many stations were read first hand to verify and augment the data set.

The other common method of determining fault plane solutions involves analysis of amplitude radiation patterns of surface waves (Rayleigh waves in this study) as a function of azimuth. The theoretical basis of modelling surface wave radiation patterns is quite mathmatically rigorous and will not be presented here. The procedure basically involves collecting Rayleigh wave amplitude data (in digital form) and plotting it as a function of azimuth, taking in to consideration propagation effects such as attenuation and dispersion. Fourier transformations are used to isolate amplitude data corresponding to desired ranges of frequencies. The resulting data is plotted and compared with theoretical radiation patterns. The observed patterns are usually azimuthally incomplete and contain variations due to non-uniform attenuation characteristics and are therefore quite jagged, but the lobe maxima and nodal characteristics are usually discernable. The radiation patterns are quite sensitive to the source fault geometry, so finding the pattern which best matches the observed data is often not a difficult task. Used in conjunction with mechanisms produced from P-wave first motion data, a well-constrained solution is often achievable.

One surface wave mechanism was attempted in this study, but the lack of available data and time constraints precluded the confident determination of a fault plane solution. The event occured on March 3, 1978 and was considered to be the master event of the relocated sequence of earthquakes occuring around 165 degrees at 55 degrees north latitude. The first motion data indicated a thrust event with one plane fairly well constrained, but the surface wave data in hand were not sufficient to substantiate or improve this determination. The waveform produced by the event appears to indicate a complex rupture history, so it is not certian that a solution even obtainable. The results of the attempt and the stations used are presented in Appendix D.

Body Wave Analysis

Body waves were analysed in this study by the generation of synthetic seismograms in order to place constraints on some of the focal parameters of three of the largest earthquakes in the Komandorsky Islands. Refinement of the focal depth, near source structure, and focal mechanism can be achieved through successful matching of observed seismograms with traces generated artificially. The procedure involves theoretically generating seismic rays taking into account effects of the focal mechanism, near source velocity structure, and source-reciever seperation. The resultant seismogram consists of theoretical pulses generated at the source and at the interfaces of the velocity structure, scaled for relative amplitudes and time delays. The method is especially useful for shallow focus earthquakes, where the effects of the near source structure are seen in the earliest parts of the seismogram.

The synthetic seismogram for teleseismic events is expressed by Kroeger and Geller (in press) as a convolution of the form:

$$u(t)=S(t)*NSS(t)*E(t)*RS(t)*I(t)$$

where u(t) is the seismogram, S(t) is the source time function of the earthquake, NSS(t) represents the effects of the focal mechanism, propagation and near source structure, E(t) is the term representing the effects of propagation through the source to the reciever, RS(t) represents the near reciever structure, and I(t) is the response of the recording instrument. The term E(t) includes the effects of geometrical spreading, analastic attenuation and travel time from the source region to the reciever region. The near reciever structure term is neglected since the near source structure has the dominant effect on the waveform produced by submarine earthquakes recorded by land-based recievers.

The main function of the synthetic seismogram routine is to calculate the near source structure term NSS(t). This term, as considered in the Kroeger-Geller algorithm, is a time series of scaled impulses, one for each ray which enters a homogeneous halfspace as a result of interaction with a velocity structure of horizontal layers in the vicinity of the source. This term is convolved with the propagation term to produce a discrete spike representation of the signal, and this in turn convolved with the source time function and appropriate instrument response to produce the synthetic seismogram. The character of each pulse (duration, symmetry) is determined by the source time function, which is altered to match the observed pulse shape. The overall waveform can be smoothed (by the removal of higher frequencies) by altering the attenuation characteristics corresponding to the raypath to a particular station.

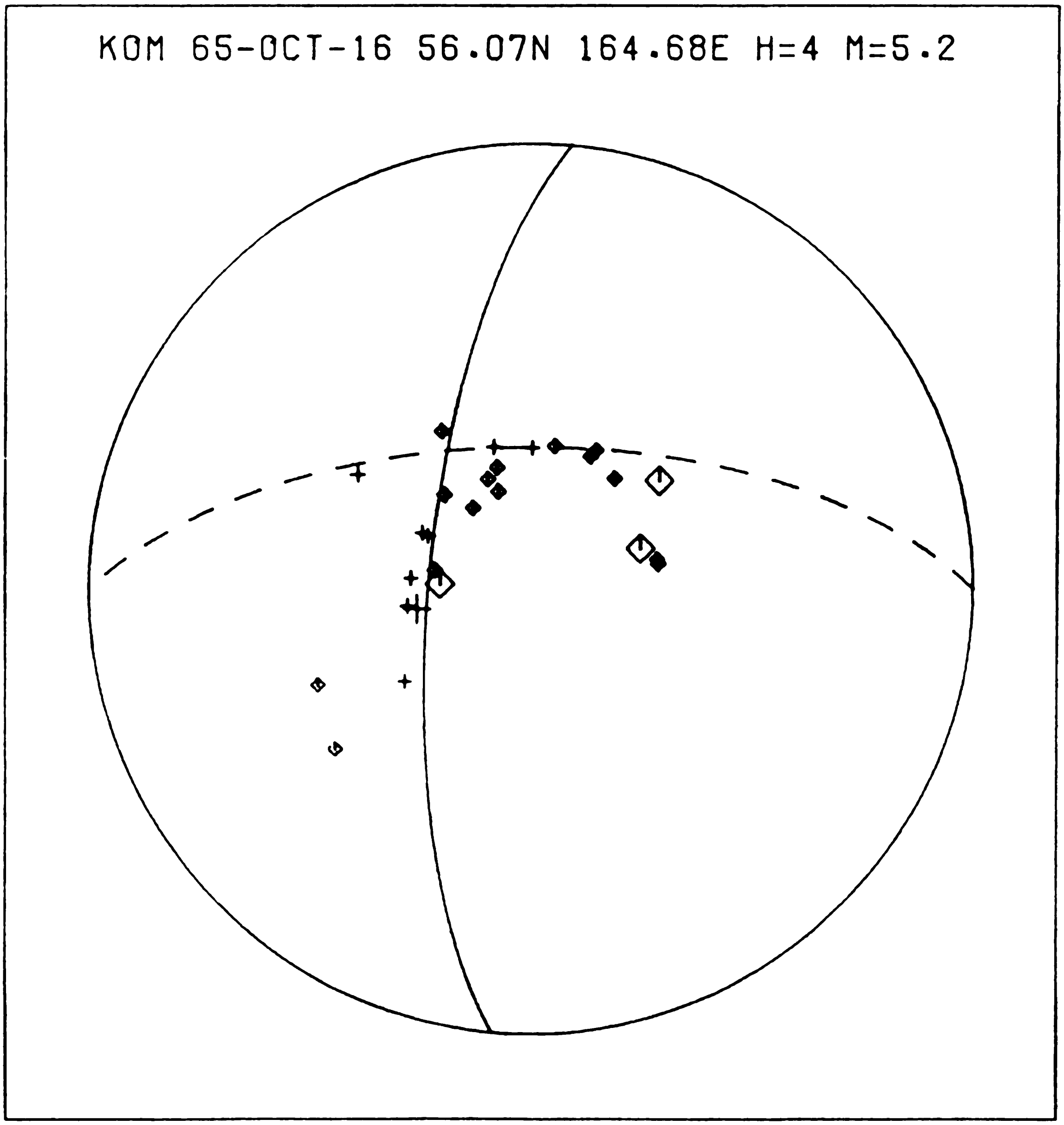
Synthetic seismogram analysis is particularly useful for obtaining constraints on the focal depth and the depth of the water over the epicenter af a submarine earthquake event. Long period waveforms are quite sensitive to the effects of the pP and pwP phases produced by earthquakes of body magnitude of roughly 5.6 and above. Of the three events analysed in this study, the event of Mb=5.8 was best suited for long period body wave analysis. The high amplitude of the waveforms produced by the 6.1 event made matching the long period records more difficult. The ISC reported 6.0 (mb) event produced very little long period body wave energy and thus was modelled on the basis of relatively few short period records. The results of this event were quite consistant however, and are presented with a high level of confidence.

The most significant error introduced in to this type of analysis is due to representation of the velocity structure in the source region. The structure of island arcs is generally complicated and variable, making velocity constraints particularly difficult to determine. Consideration of this imprecision, coupled with the uncertainty involved in matching waveforms implies that depth determinations will be accurate to only a few kilometers (5-7 km as suggested by Wiens and Stein, 1983 and Hong and Fujita, 1981).

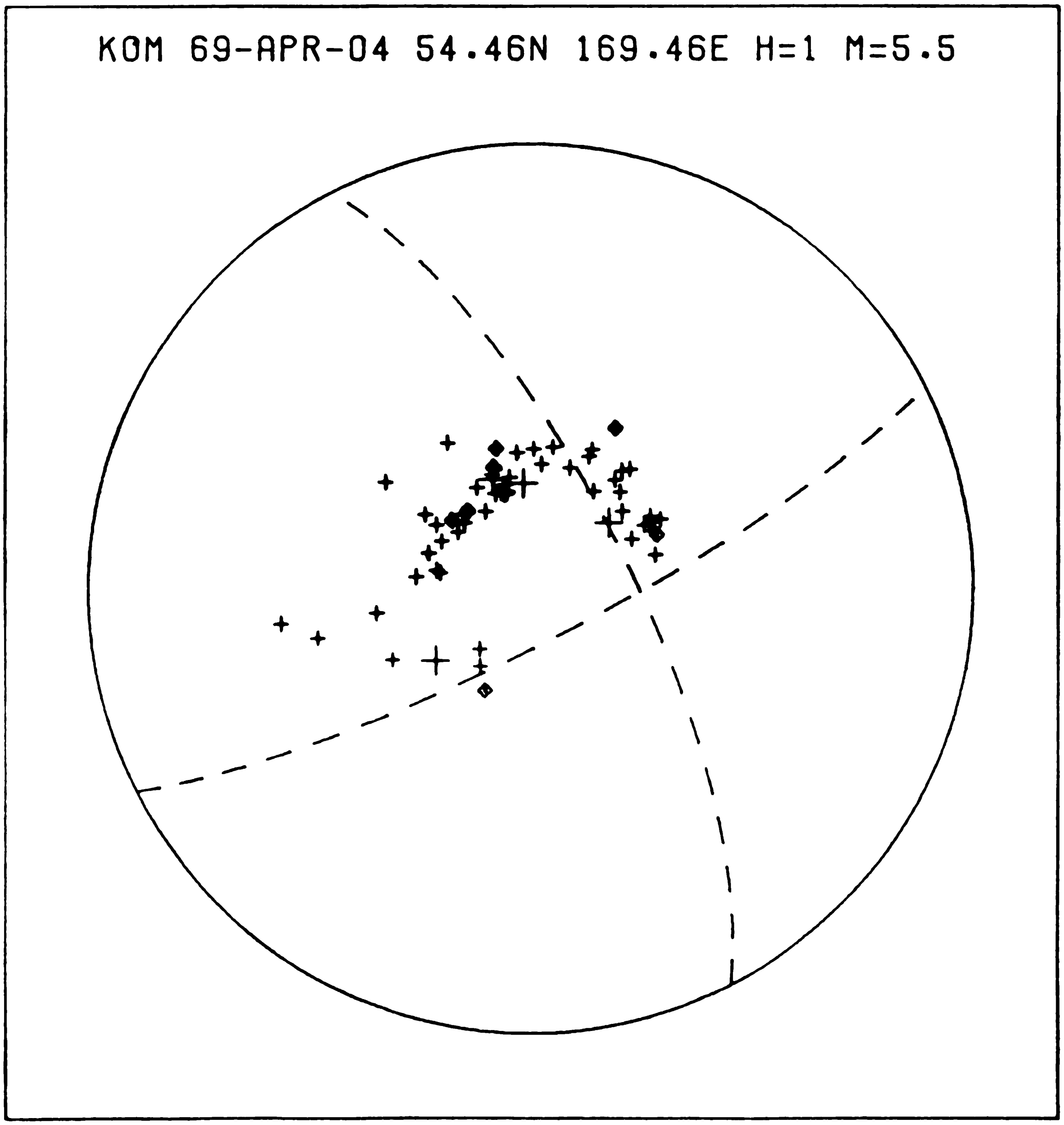
APPENDIX C

Focal Mechanisms

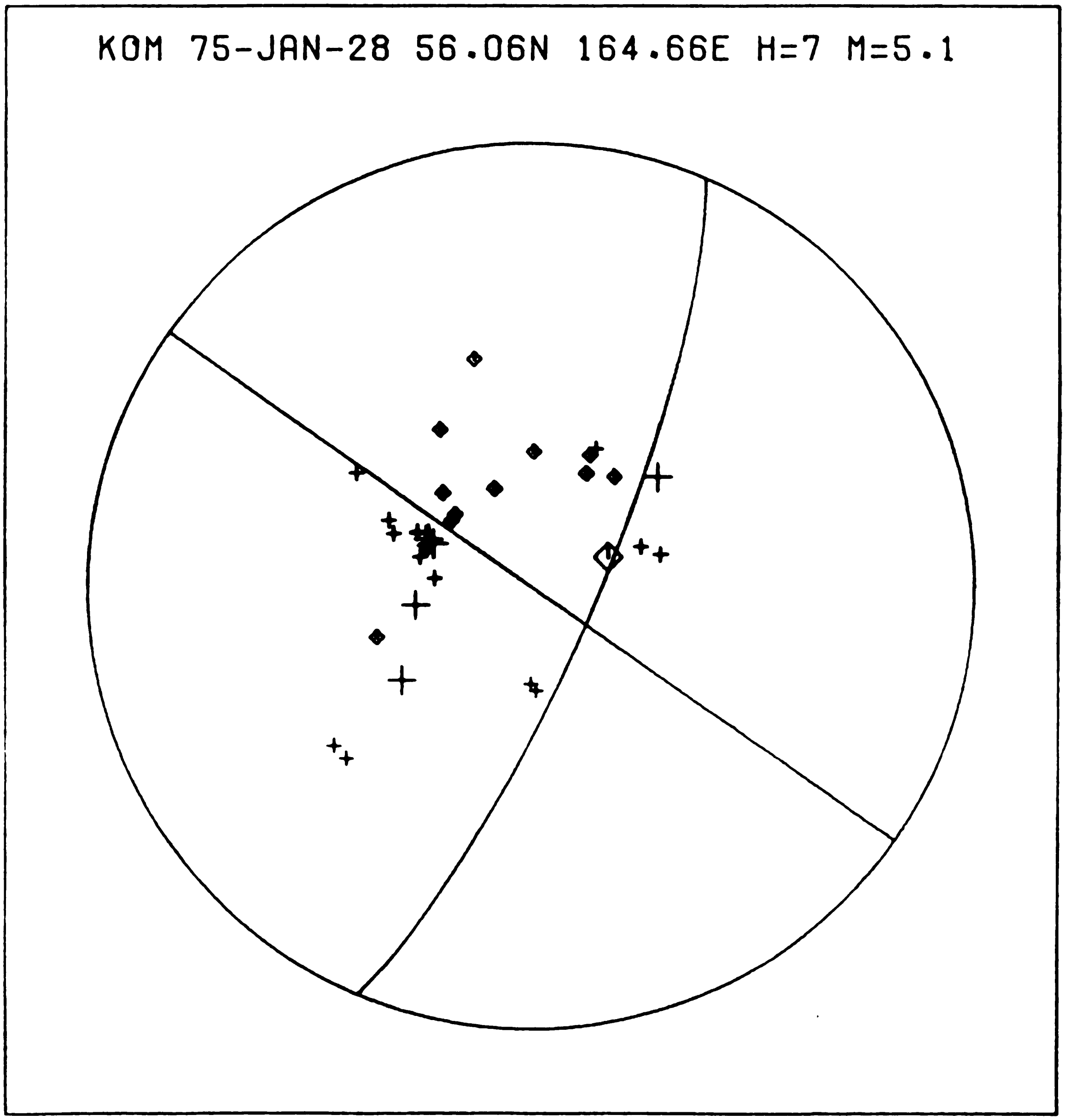
The following figures reprisent fault plane solutions determined in this study by means of plotting compressional wave first motions in a lower hemisphere stereographic projection of the focal sphere. Compressional first motions are represented by crosses and dilitational first motions by diamonds. The larger symbols indicate data read first hand, the smaller symbols are picks from the ISC and USGS bulletins. Planes are dashed where uncertain.



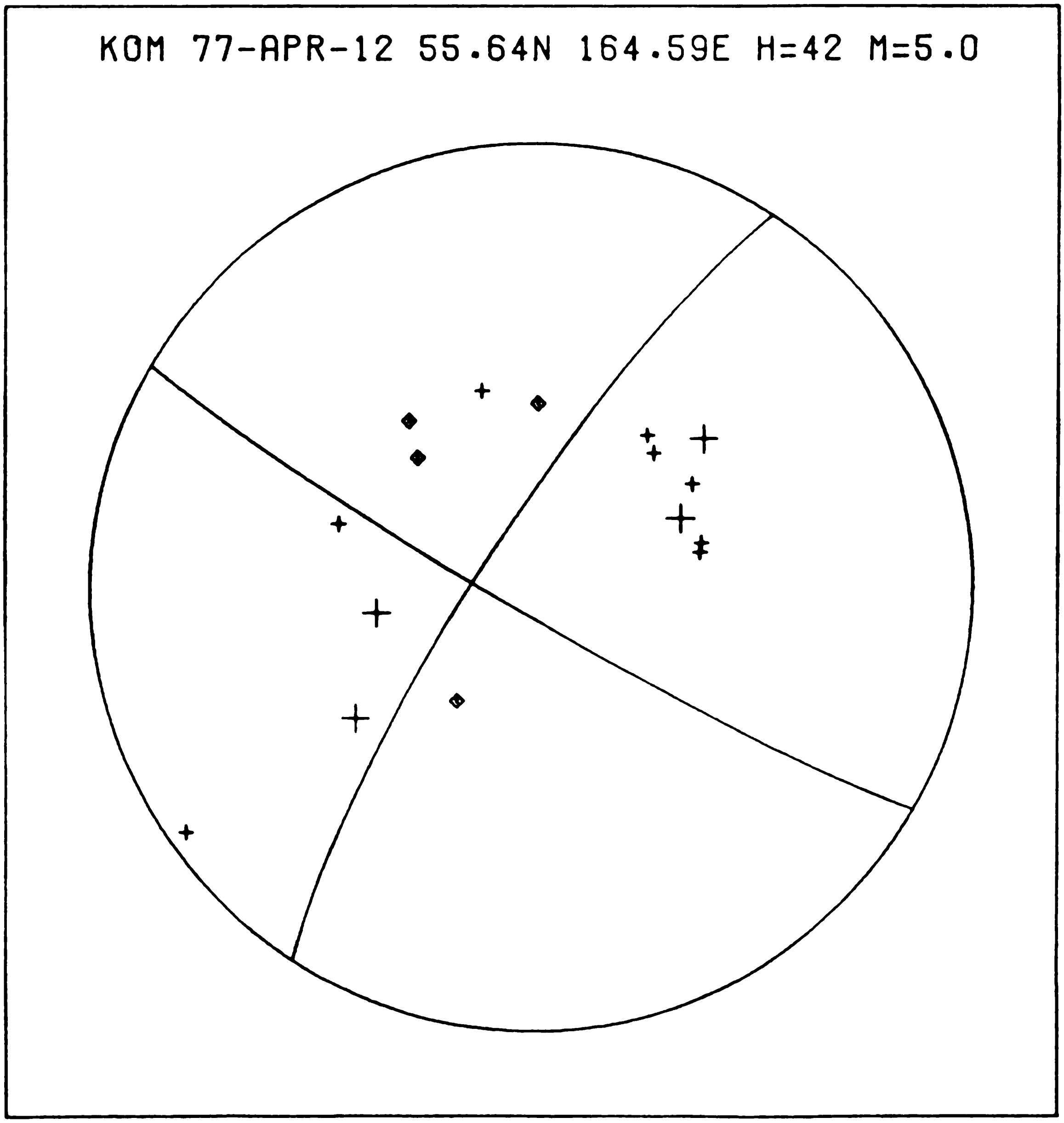
I



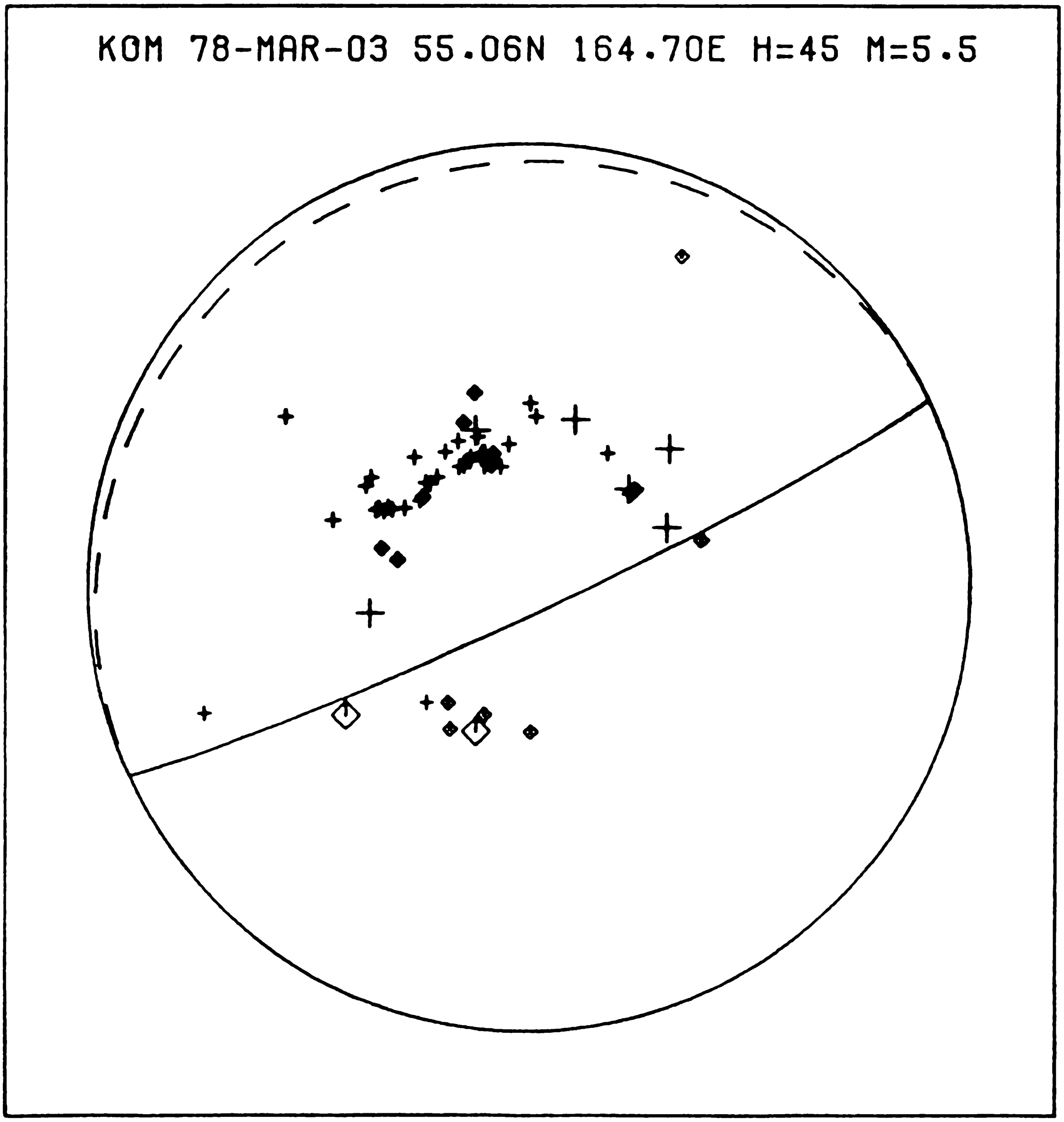
2



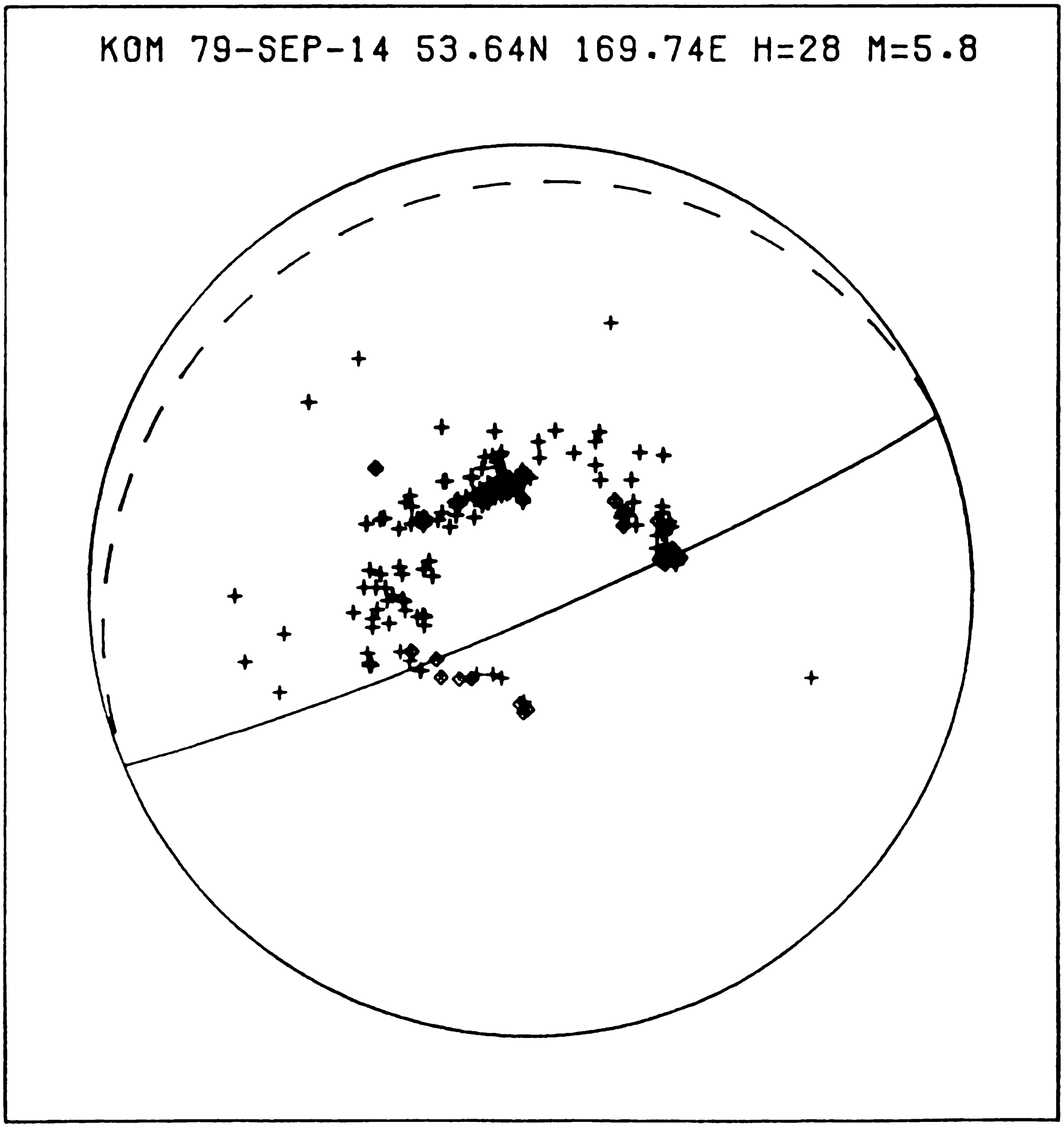
3



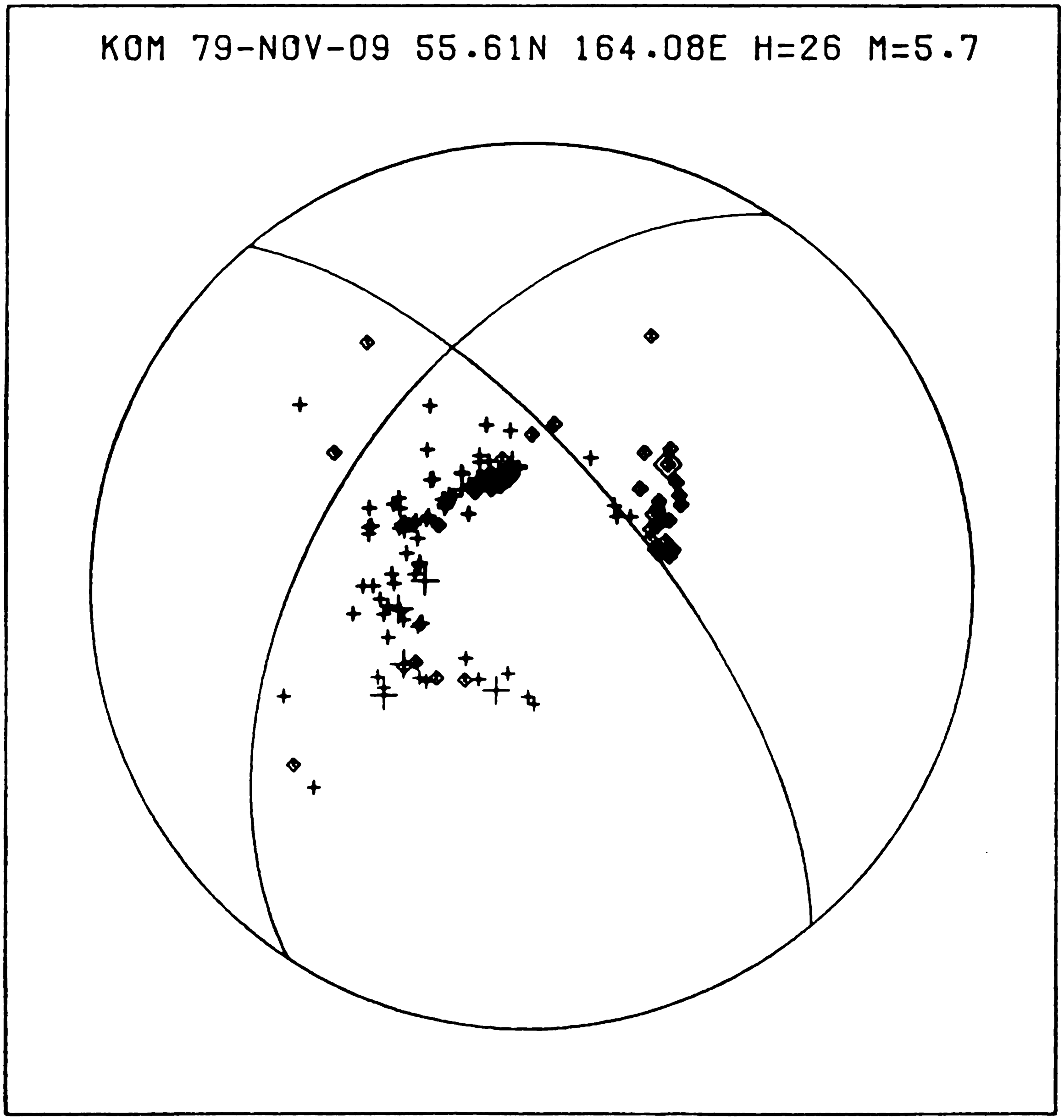
4



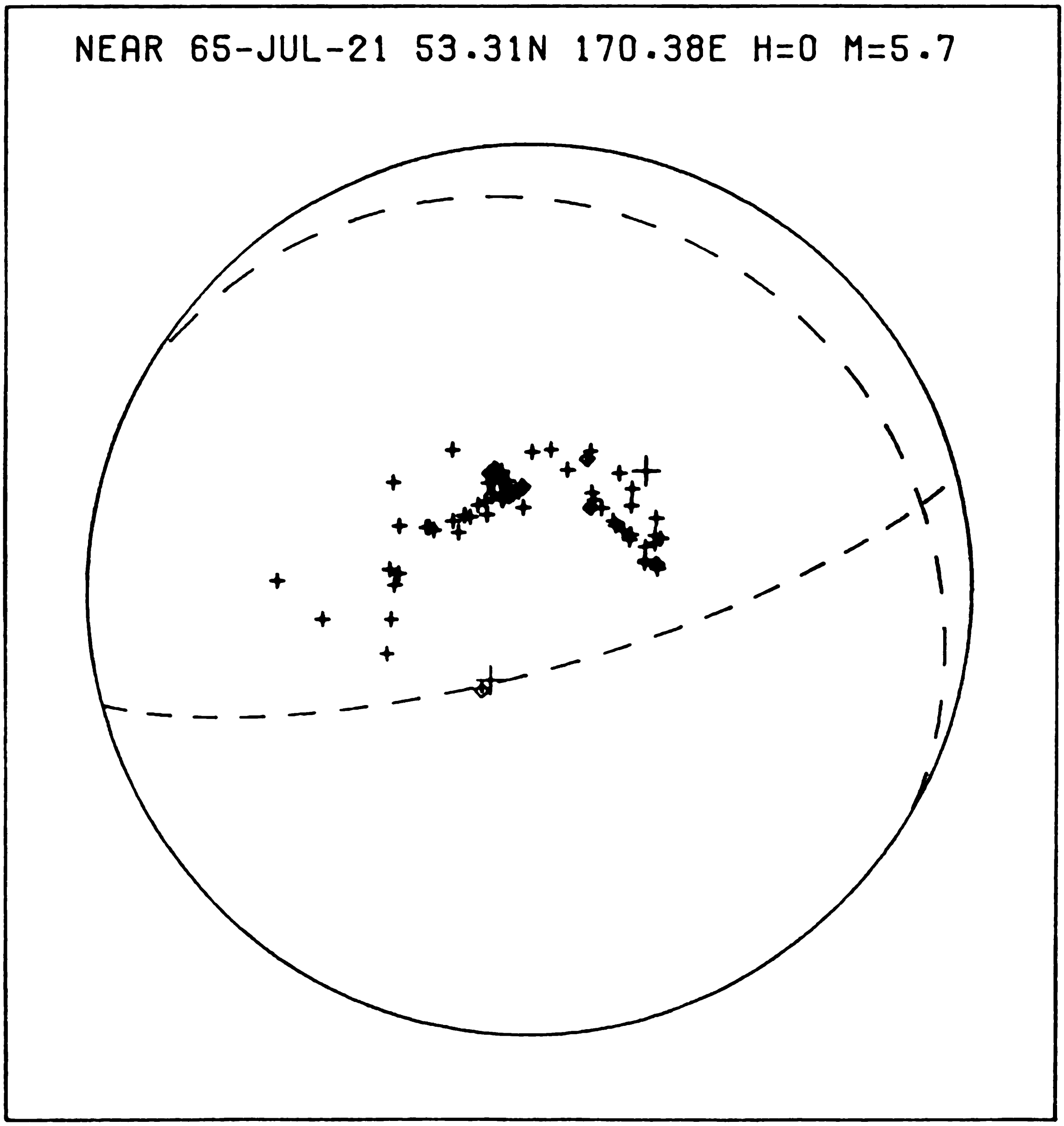
5



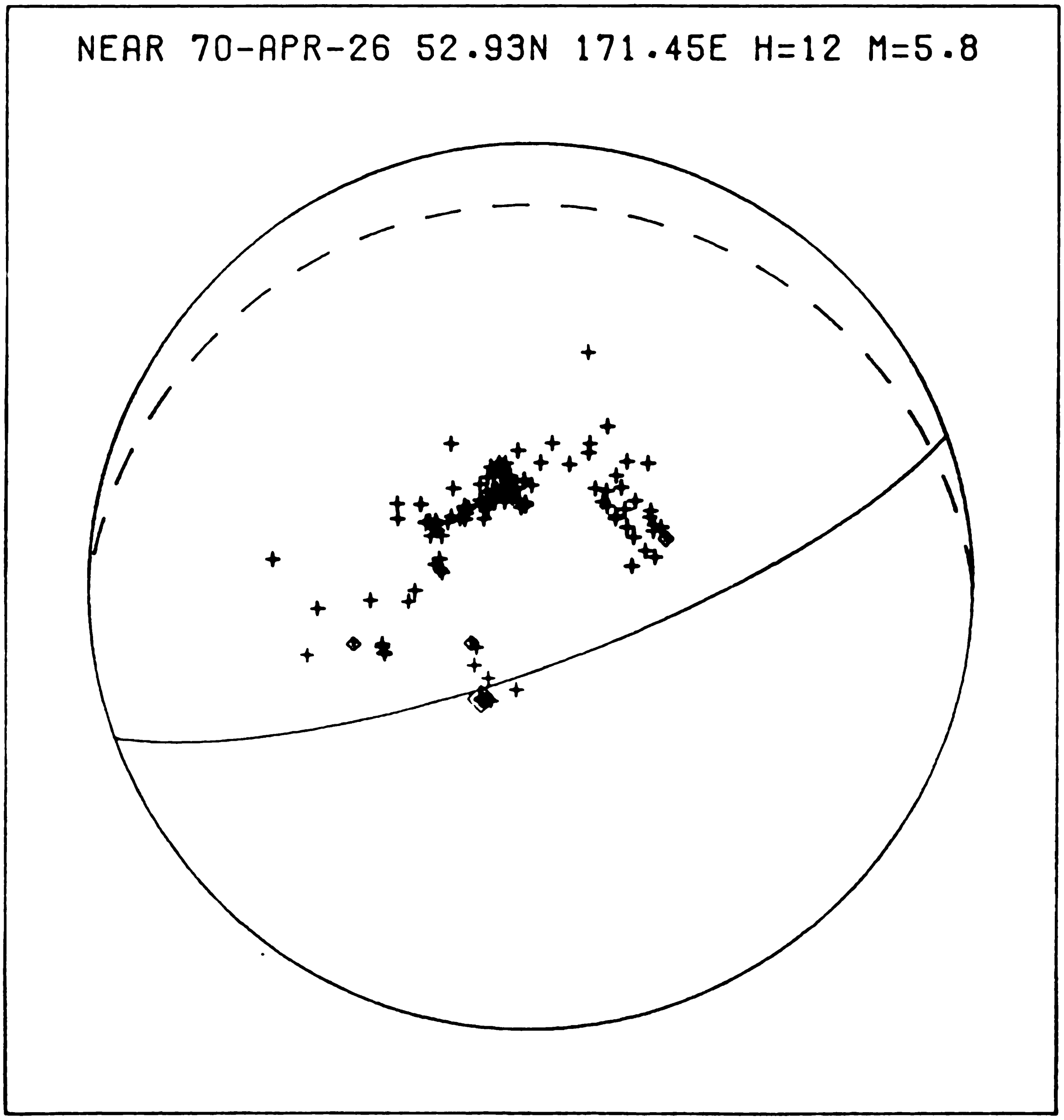
6



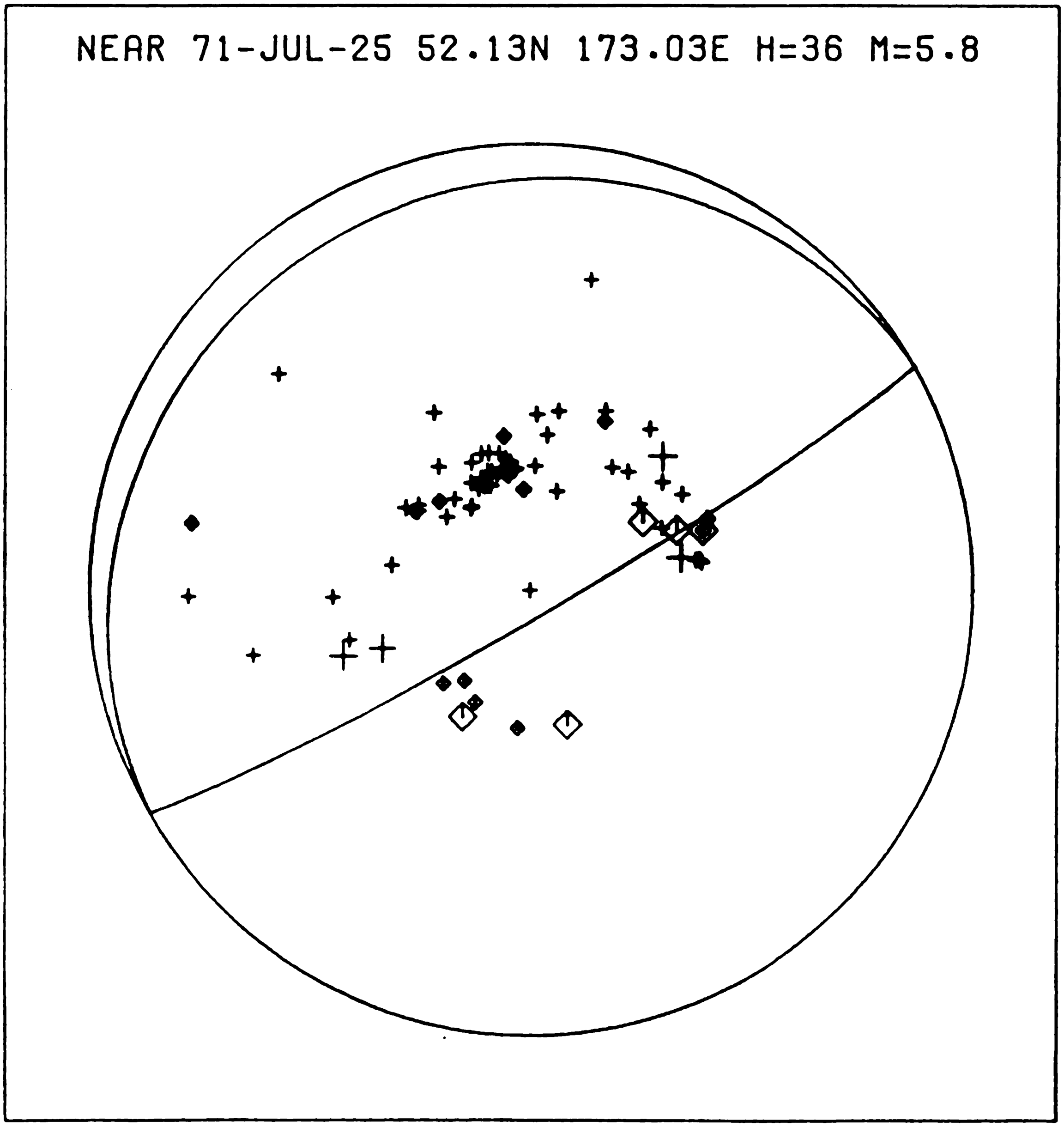
7



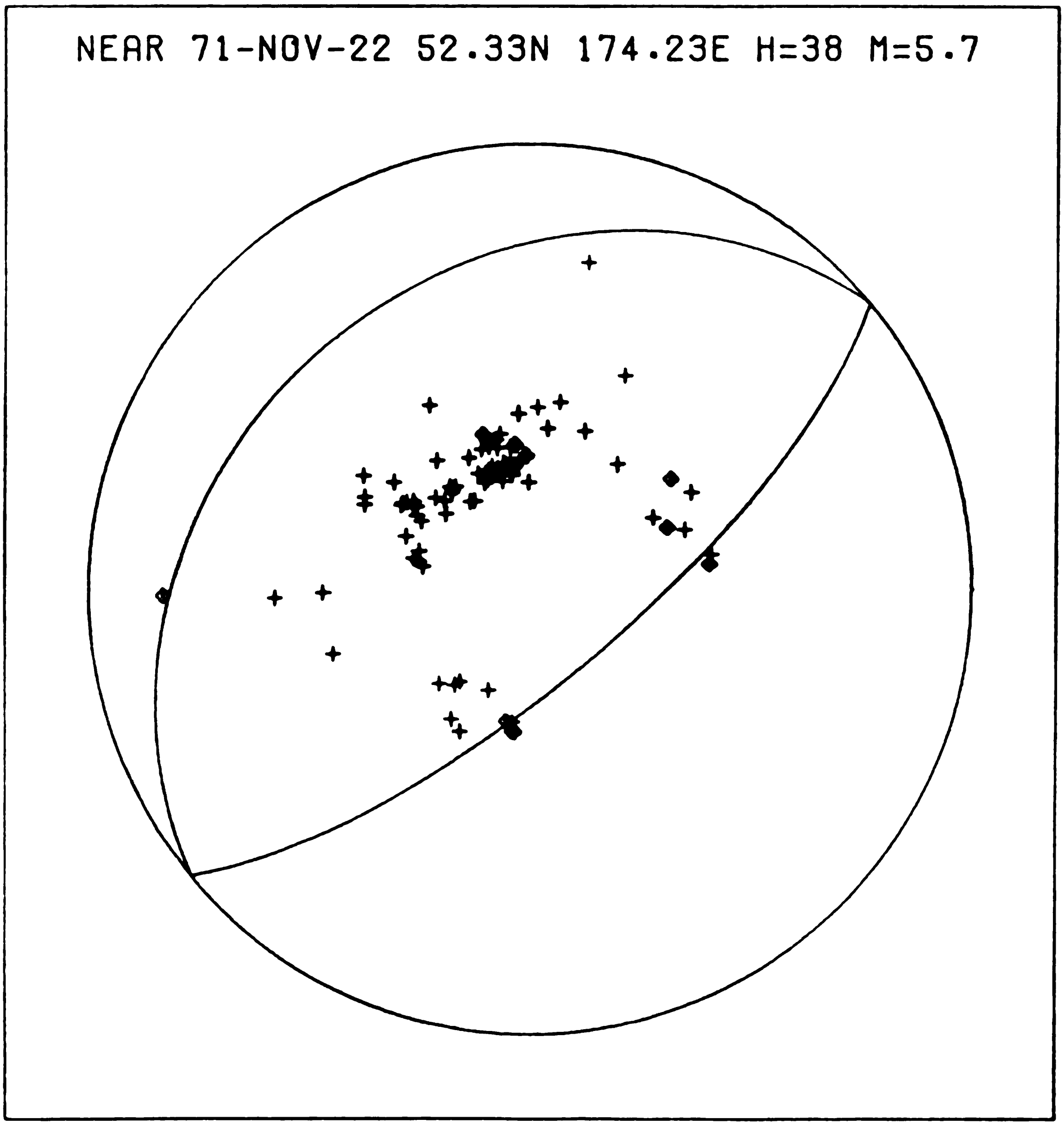
8



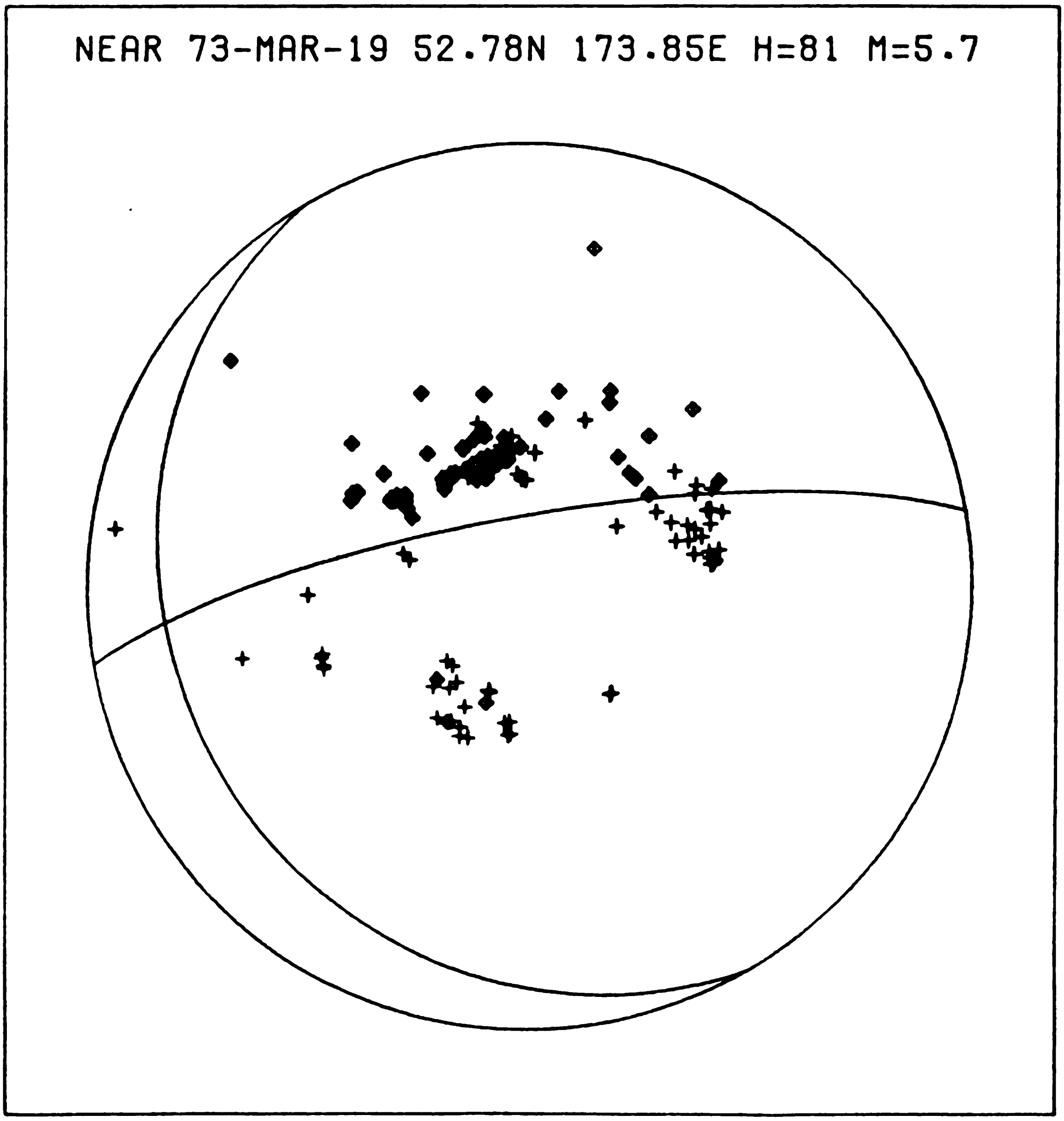
9



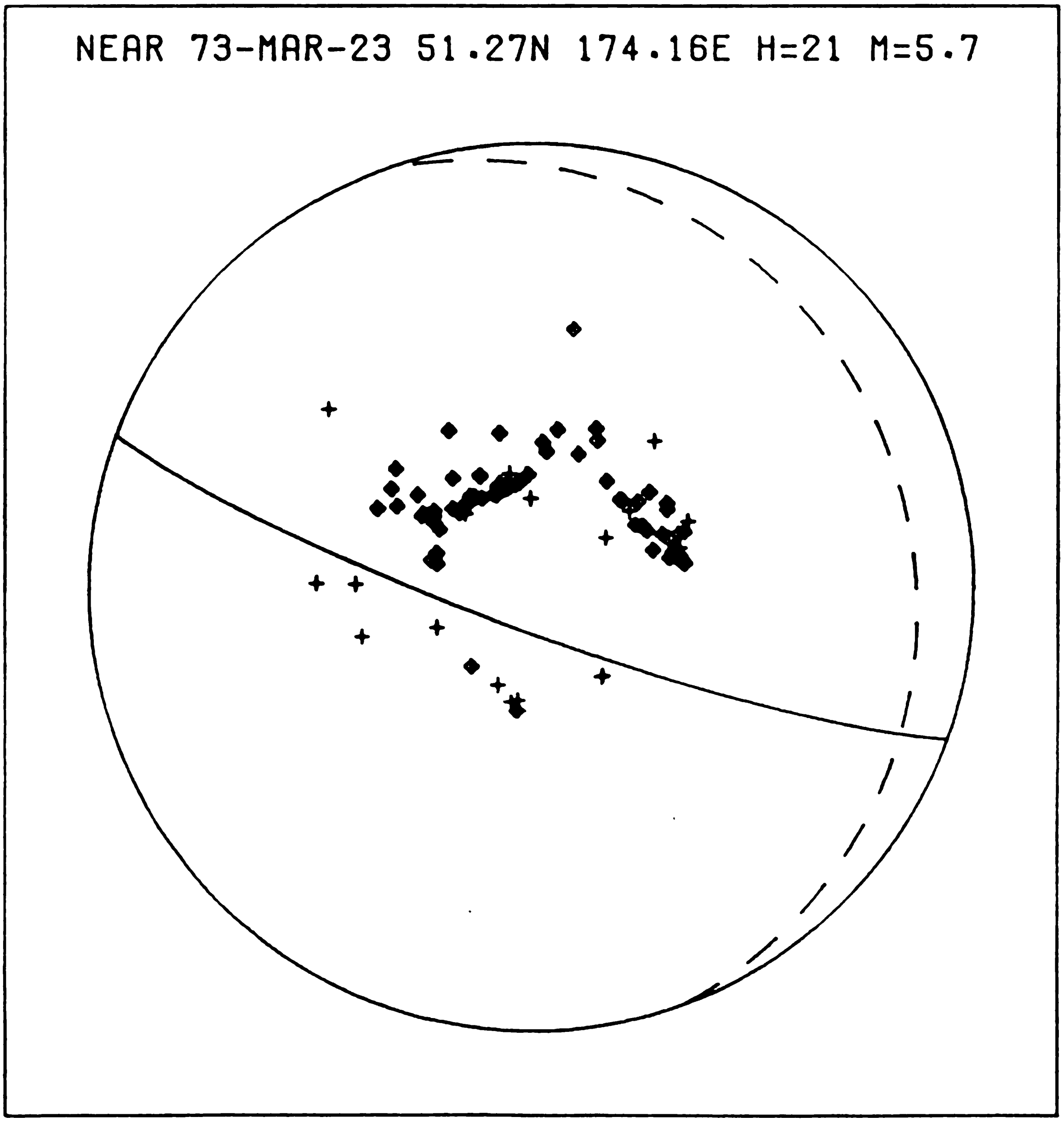
10



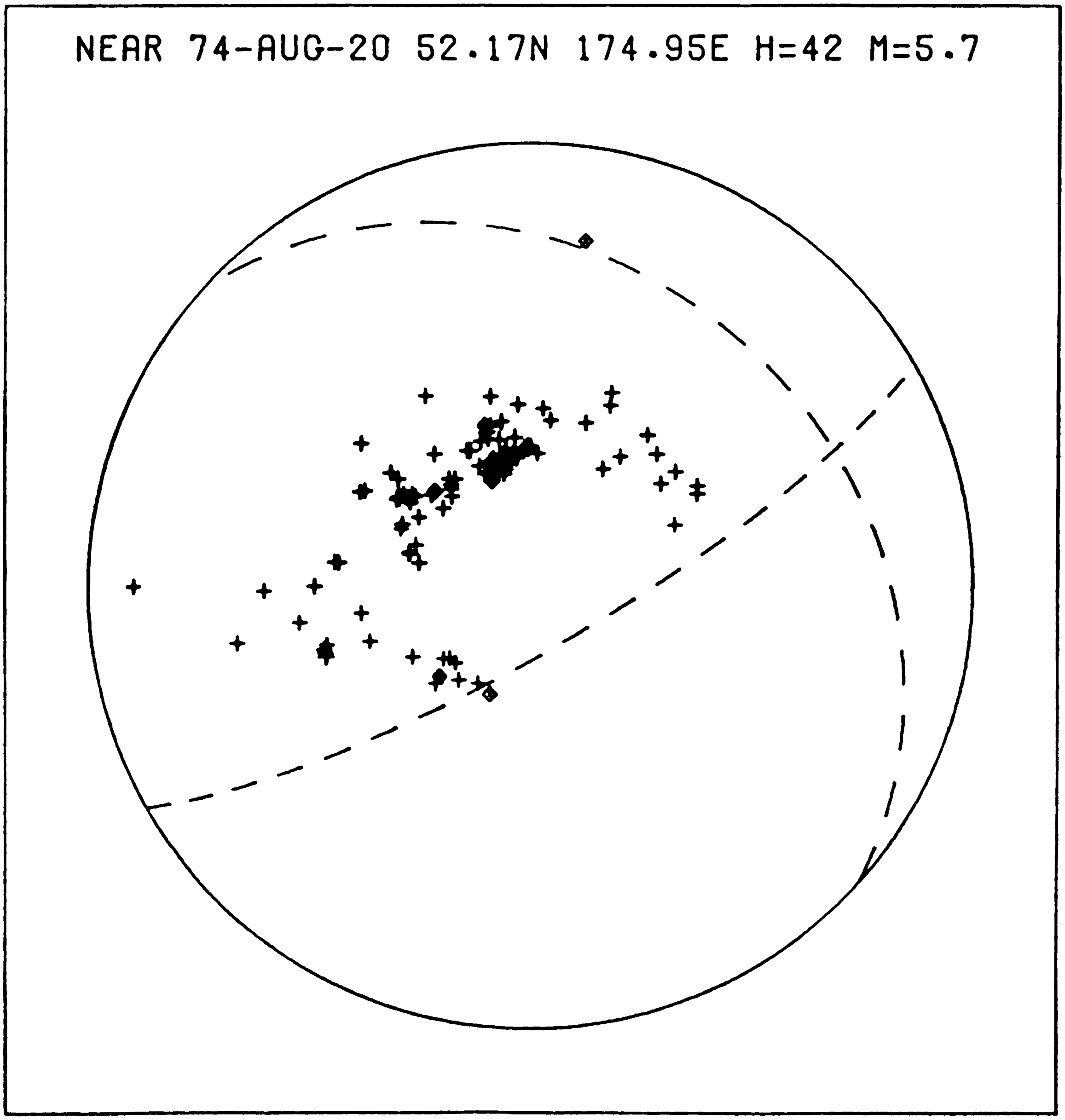
11



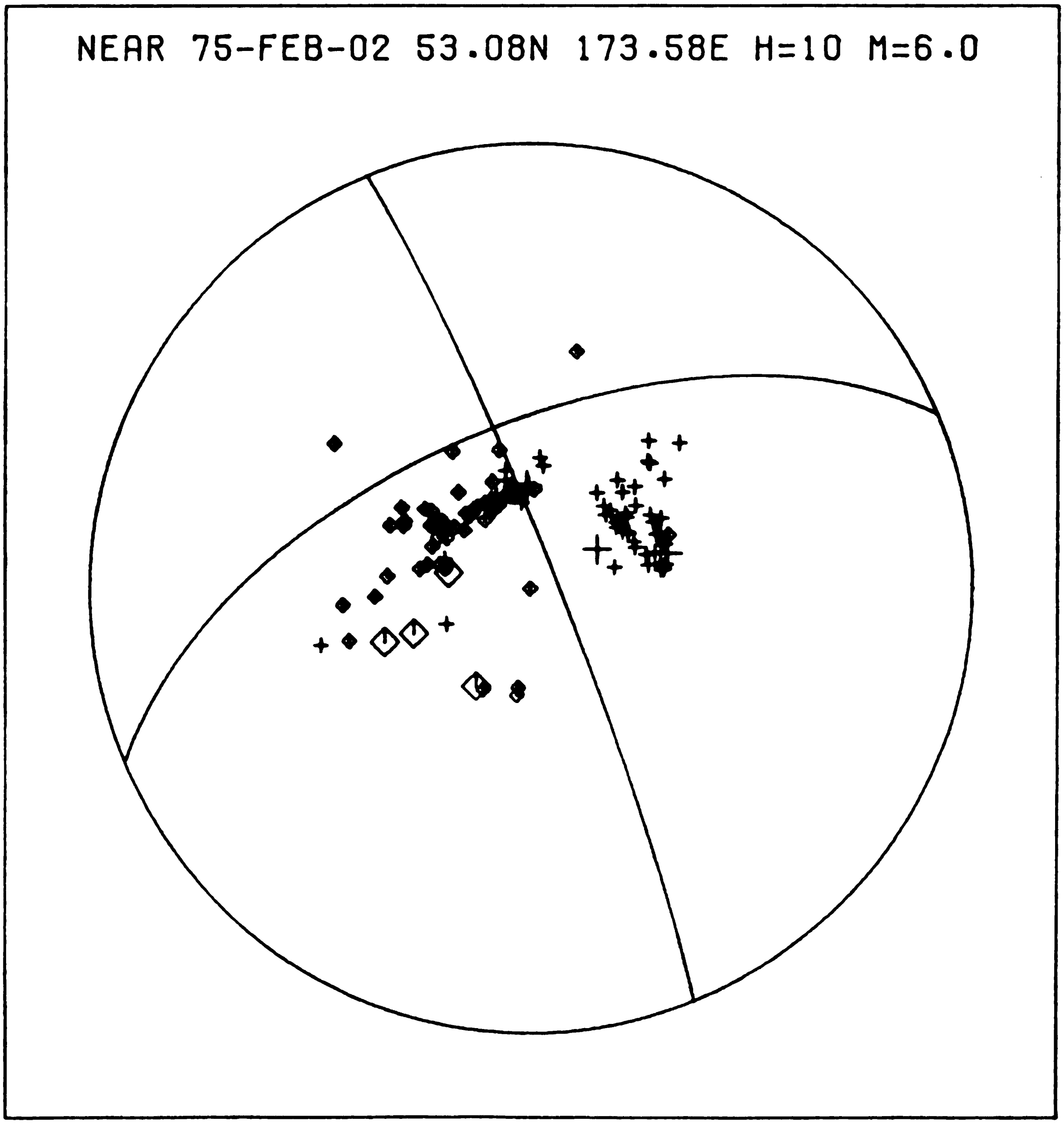
12



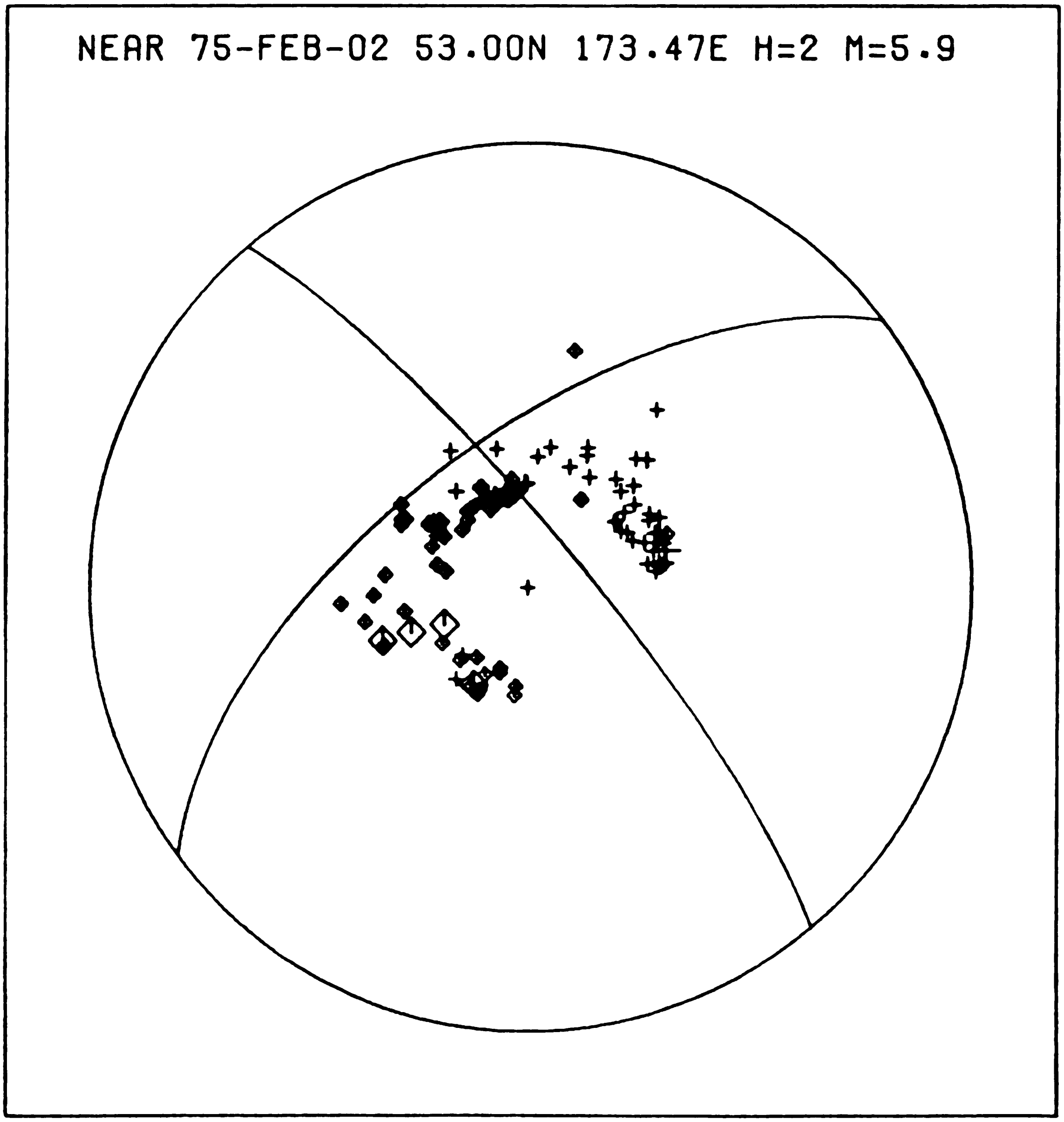
13



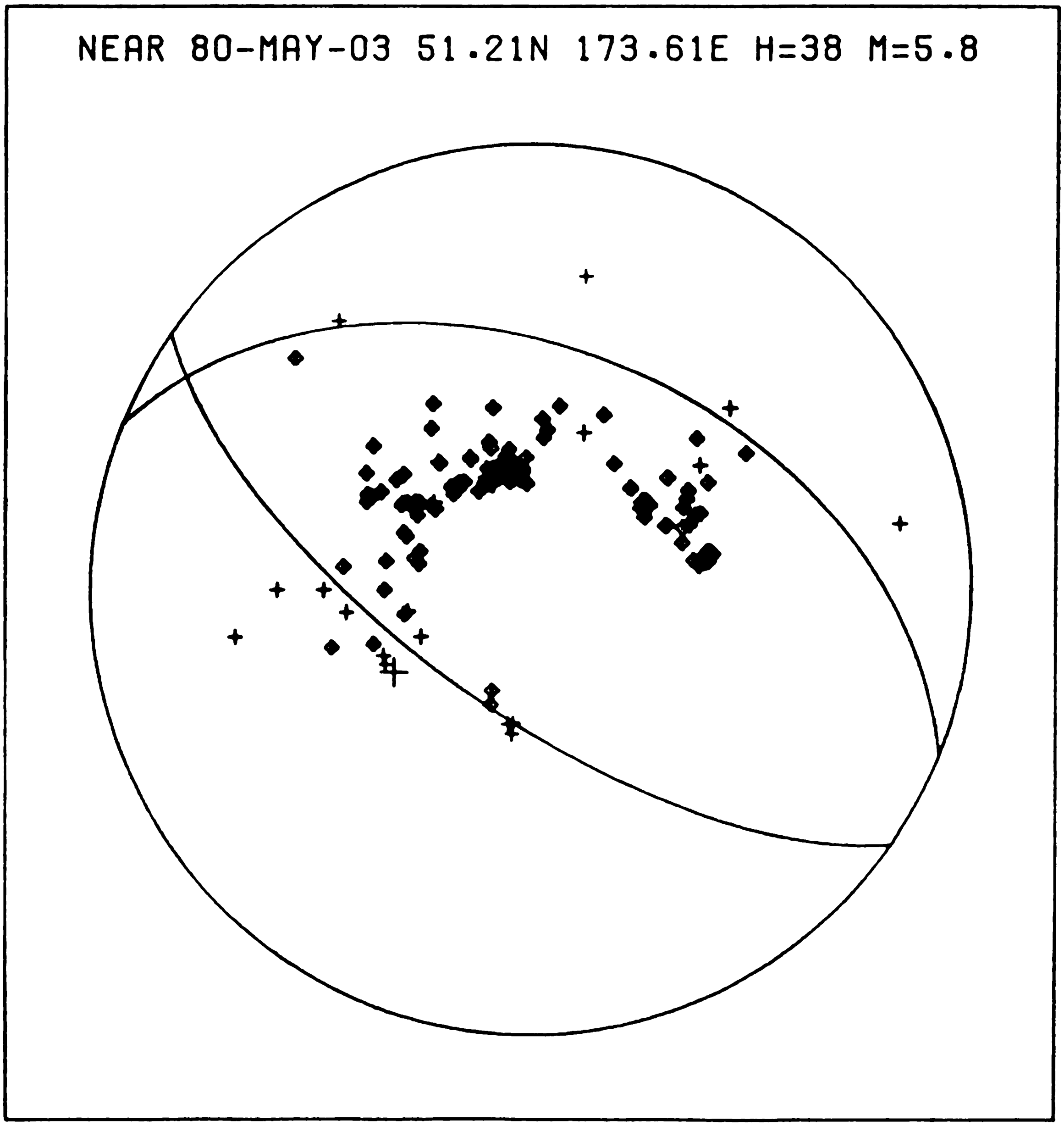
14



15



16

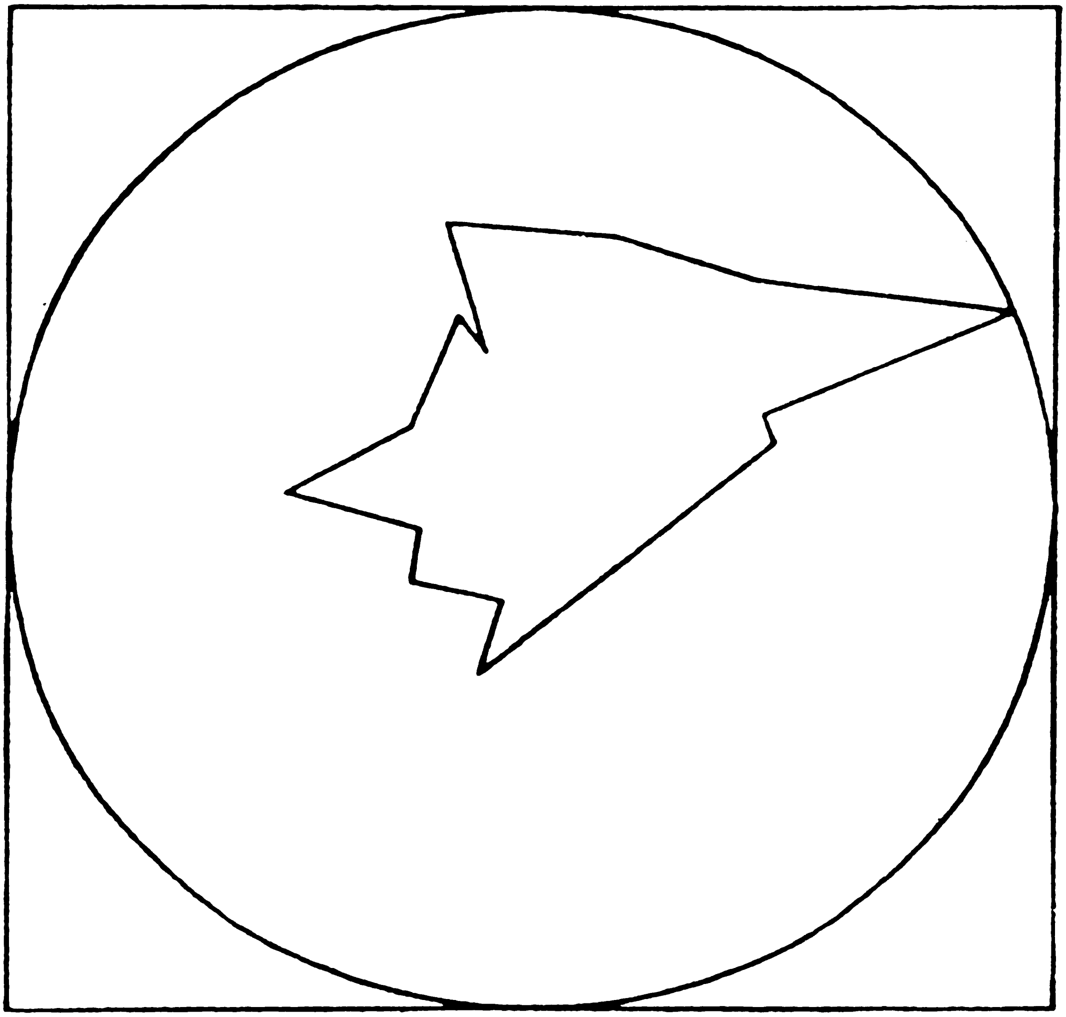


17

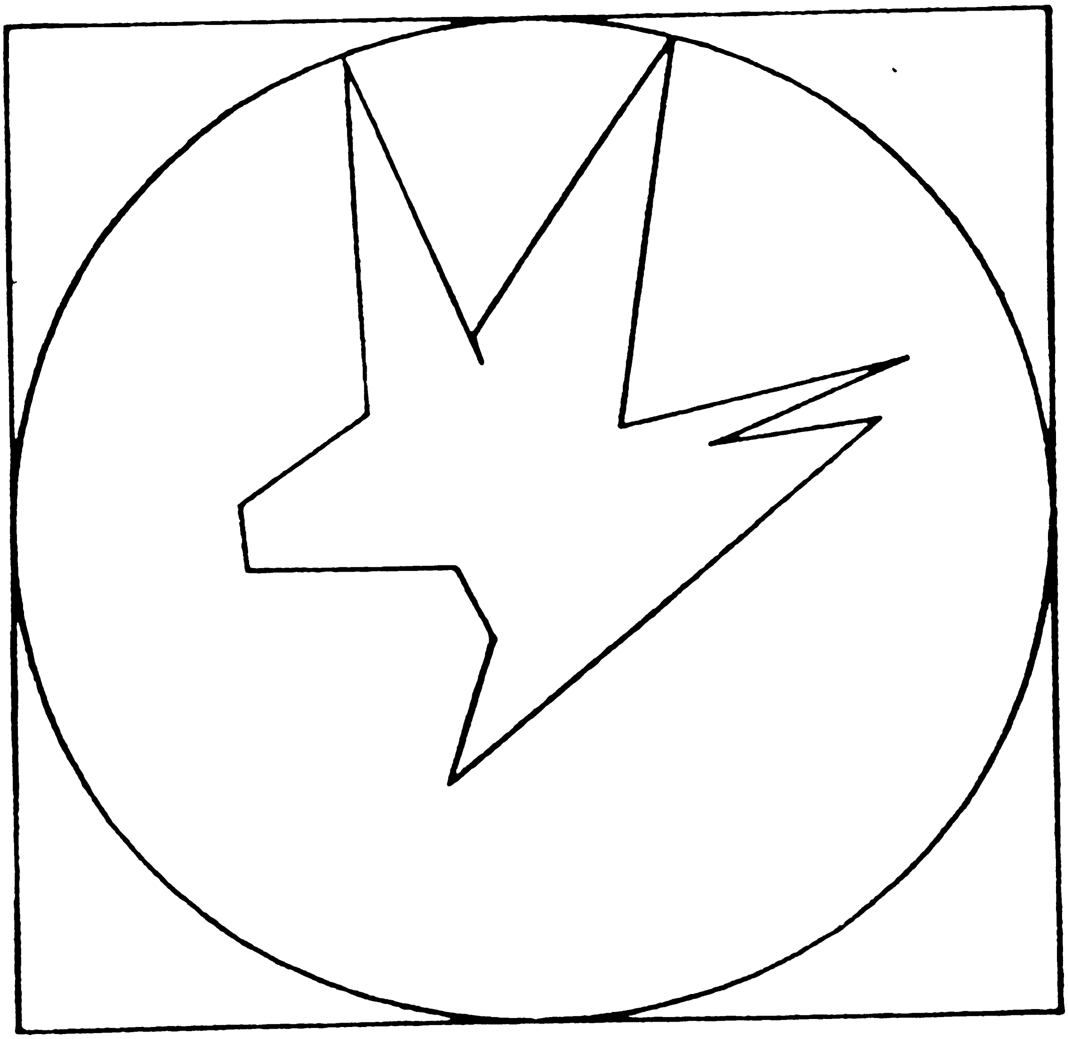
APPENDIX D

Surface Wave Mechanism

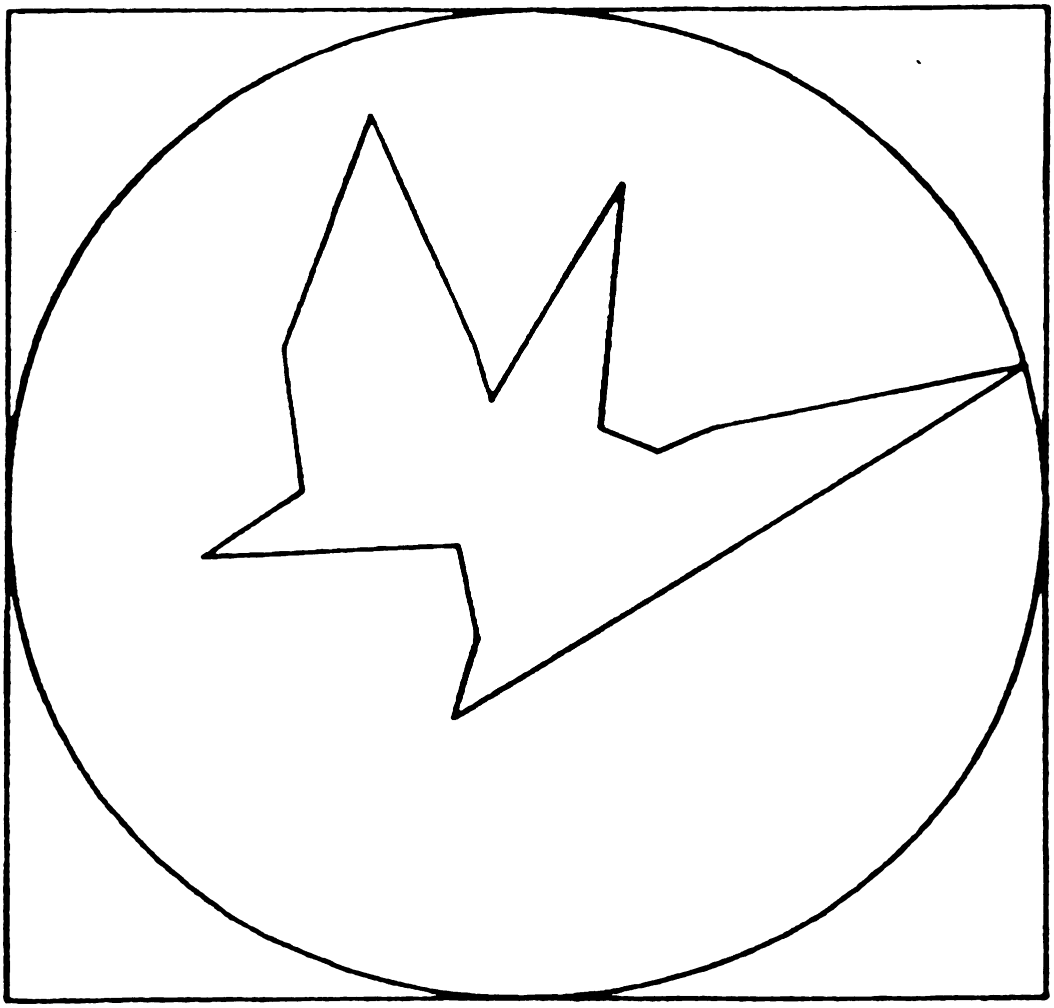
An attempt was made to determine a fault plane solution using Rayleigh wave radiation patterns for the earthquake of March 3, 1978. Time considerations and lack of sufficient data resulted in a poorly constrained solution. The results of analysis using 14 long period vertical station records appear on the following pages.



STRIKE= 0 DIP= 0 SLIP= 0
T= 23 SEC
RAYLEIGH WAVES



STRIKE= 0 DIP= 0 SLIP= 0
T= 33 SEC
RAYLEIGH WAVES



STRIKE= 0 DIP= 0 SLIP= 0
T= 45 SEC
RAYLEIGH WAVES

LIST OF REFERENCES

LIST OF REFERENCES

Ben-Avraham, Z., and A. K. Cooper, Early evolution of the Bering Sea by collision of oceanic rises and north Pacific subduction zones, Geol. Soc. Amer. Bull., 92, 485-495, 1981.

Borsuk, A. M., and A. A. Tsvetkov, Magmatic associations of the western part of the Aleutian Island Arc, Internat. Geol. Rev., Engl. Transl., 24, 317-329, 1982.

Chapman, M. E., and S. C. Solomon, North American-Eurasian plate boundary in northeast Asia, J. Geophys. Res., 81, 921-930, 1976.

Coats, R. R., W. H. Nelson, R. Q. Lewis, and H. A. Powers, Geologic reconnaissance of Kiska Island, Aleutian Islands, Alaska, U. S. Geol. Surv. Bull., 1028-R, 563-581, 1961.

Cooper, A. K., M. S. Marlow, and Z. Ben-Avraham, Multichannel seismic evidence bearing on the origin of Bowers Ridge, Bering Sea, Geol. Soc. Amer. Bull., 92, 474-484, 1981.

Cormier, V. F., Tectonics near the junction of the Aleutian and Kurile-Kamchatka arcs and a mechanism for Middle Tertiary magmatism in the Kamchatka Basin, Geol. Soc. Amer. Bull., 86, 443-453, 1975a.

Cormier, V. F., Composite focal mechanism solution of the Near Islands (Aleutian Islands) earthquakes of February 2, 1975 (abstract), Eos Trans. AGU, 56, 393, 1975b.

DeLong, S. E., P. J. Fox, and F. W. McDowell, Subduction of the Kula Ridge at the Aleutian Trench, Geol. Soc. Amer. Bull., 89, 83-95, 1978.

Evernden, J., Further studies on seismic discrimination, Bull. Seimol. Soc. Amer., 65, 359-391, 1975.

Farmer, R. A., Seismicity, tectonics and focal mechanisms in the Scotia Sea area, M. S. Thesis, Mich. State Univ., 1982.

Gates, O., H. A. Powers, and R. E. Wilcox, Geology of the Near Islands, Alaska, U. S. Geol. Surv. Bull. 1028-U, 709-821, 1971.

Gaynanov, A. G., I. P. Kosminskaya, and P. A. Stroyev, Geophysical studies of the deep structure of the Bering Sea, Acad. Sci. USSR, Izv., Earth Phy. Ser., nr. 8, 461-465, 1968.

Habermann, R. E., Teleseismic detection in the Aleutian Island Arc, J. Geophys. Res., 88, 5056-5064, 1983.

Harland, W. B., A. V. Cox, P. G. Llewellyn, C. A. G. Pickton, A. G. Smith, and R. Walters, A Geologic Time Scale, 131 pp., Cambridge Univ. Press, Great Britian, 1982.

Hong, T.-L., and K. Fujita, Modelling of depth phases and source processes of some Central Aleutian earthquakes, Earth Planet. Sci. Lett., 53, 333-342, 1981.

Jacob, K. H., Aleutian seismic gaps quantified: High probability for great Shumagin earthquake in next 10 years (abstract), Eos Trans. AGU, 64, 258, 1983.

Jeffries, H., and K. E. Bullen, Seismological Tables, 50 pp., Neill & Co. Ltd., Edinburgh, 1940.

Kanamori, H., and J. Cipar, Focal process of the Great Chilean Earthquake of May 22, 1960, Phys. Earth Planet. Inter., 9, 128-136, 1974.

Kroeger, G. C., and R. J. Geller, An efficient method for synthesizing teleseismic body waves in a vertically stratified medium, (in press).

Marlow, M. S., and A. K. Cooper, Wandering terranes in southern Alaska: The Aleutia microplate and implications for the Bering Sea, J. Geophys. Res., 88, 3439-3446, 1983.

Minster, J. B., and T. H. Jordan, Present-day plate motions, J. Geophys. Res., 83, 5331-5354, 1978.

Murdock, J. N., Crust-mantle system in the central Aleutian region: A hypothesis, Bull. Seismol. Soc. Amer., 59, 1543-1558, 1969.

Pho, H. T., and L. Behe, Extended distances and angles of incidence of P waves, Bull. Seismol. Soc. Amer., 62, 885-902, 1972.

Rabinowitz, P. D., and A. K. Cooper, Structure and sediment distribution in the western Bering Sea Basin, Marine Geology, 24, 309-320, 1977.

Ringwood, A. E., The petrological evolution of island arc systems, J. Geol. Soc. Lond., 130, 183-204, 1974.

Schmidt, O. A., Tektonika Komandorskikh ostrovov i struktura Aleutskoi griady, Akad. Nauk SSSR Geol. Institut, Trudy, vyp. 320., 100 pp., 1978.

Shor, G. G. Jr., Structure of the Berings Sea and the Aleutian Ridge, Marine Geology, 1, 213-219, 1964.

Simkin, T., L. Siebert, L. McClelland, D. Bridge, C. Newhall, and J. H. Latter, Volcanoes of the World, 232 pp., Smithsonian Institution, Hutchinson Ross Publ. Co., Stroudsburg, PA, 1981.

Spence, W., The Aleutian Arc: Tectonic blocks, episodic subduction, strain diffusion, and magma generation, J. Geophys. Res., 82, 213-230, 1977.

Stauder, W., Mechanism of the Rat Island earthquake sequence of February 4, 1965, with relation to island arcs and sea-floor spreading, J. Geophys. Res., 73, 3847-3858, 1968.

Stewart, R. J., J. H. Natland, and W. R. Glassley, Petrology of volcanic rocks recovered on DSDP leg 19 from the north Pacific Ocean and the Bering Sea, in Creager, J. S., D. W. Scholl, et al., Initial Reports of the Deep Sea Drilling Project, Volume 19, pp. 615-627, Washington(U. S. Government Printing Office), 1973.

Stone, D. B., Geophysics in the Bering Sea and surrounding areas: A review, Tectonophysics, 6, 433-460, 1968.

Stone, D. B., B. C. Panuska, and D. R. Packer, Paleolatitudes versus time for southern Alaska, J. Geophys. Res., 87, 3697-3707, 1982.

Sykes, L. R., J. B. Kisslinger, L. S. House, J. N. Davies, and K. H. Jacob, rupture zones and repeat times of great earthquakes along the Alaska-Aleutian Arc, in Earthquake Prediction, edited by D. W. Simpson and P. G. Richards, pp. 73-80, American Geophysical Union, Washington, D. C., 1981.

Tsvetkov, A. A., First data on rare-earth elements in igneous rocks of the Komandor Islands, Acad. Sci. USSR, Dokl., earth Sci. Ser., Engl. Transl., 251, 184-187, 1980.

Tsvetkov, A. A., Pseudodikes in rhyolite of the Komandorskiy Islands, Int. Geol. Rev., Engl. Transl., 24, 313-316, 1982.

Wiens, D. A., and S. Stein, Age dependence of oceanic intraplate seismicity and implications for lithospheric evolution, J. Geophys. Res., 88, 6455-6468, 1983.