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Seismicity, Tectonics and Focal Mechanisms
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SEISMICITY, TECTONICS AND FOCAL MECHANISMS

IN THE SCOTIA SEA AREA

by

Randall Allen Farmer

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ABSTRACT

SEISMICITY, TECTONICS, AND FOCAL MECHANISMS IN THE SCOTIA SEA AREA

by

Randall Allen Farmer

Relocations are made of earthquakes in the Scotia Sea region, and focal mechanisms are presented. Seismicity suggests that two types of boundaries exists in this area: narrow width zones and wide, diffuse zones. Southwest Chile (and its continuation, the westernmost North Scotia boundary), the South Scotia Ridge, the Shackleton, South Sandwich and 59.5S fracture zones are narrow seismically, inferred to be strike-slip plate boundaries. The North Scotia and Aluk Ridges are diffuse seismically, inferred to be intraplate zones of weakness. The Shackleton and Aluk ridges are shown to be strike-slip in nature. Calculations show the rates of slip along the zones of weakness are 1/4 the rates along the plate boundaries. The 59.5S fracture zone is shown to represent a right-lateral strike-slip fault, suggesting that the southern arc subduction is faster than that of the plate to the north, opposite of what would be expected.

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INTRODUCTION

The Scotia Sea, located between the Antarctic and South American continents, is surrounded by seismically active and tectonically complex margins. Only one previous study of seismicity in the entire Scotia Sea area has previously been made (Forsyth, 1975), covering earthquakes between 1963 and 1973. Because of its position in the southern hemisphere there is poor seismograph station coverage, especially in the southwest and north-northeast quadrant of the focal sphere making the examination process difficult.

The purpose of this thesis is to refine the seismotectonic analyses made by Forsyth (1975) and Brett (1977) by using a larger data set and including relocation of historical (1920 - 1963) earthquakes, analysis of Rayleigh wave radiation patterns and the study of composite focal mechanisms. Problems examined include the nature of the Aluk Ridge zone of seismicity, the existance of a separate Scotia plate, the nature of the north Scotia Sea zone of seismicity, the meaning of the Nov. 20, 1974 and Aug. 26, 1978 earthquakes and the problem of slip and convergence rates around the Scotia Sea. Also considered will be the possibility that the Aluk Ridge and Shackleton fracture zone seismicity are generated by one tectonic feature. From this analysis new inferences about the plate boundaries and rates of motion in the Scotia Sea area will be constructed. The seismicity of the Scotia Sea will be compared to two other similarly active regions on the globe: the Caribbean Sea and the Macquarie Ridge.

Data for this study consist of preliminary location, time and first motion data from the ISS (International Seismological Summary), ISC (International Seismological Center) and USGS (United States Geological Survey) bulletins. First motions and surface wave waveforms were read from WWSSN (World Wide Seismological Station Network) film chips for specific key earthquakes, a single event relocation program was used for relocation of historic (pre-1963) earthquakes, and a Rayleigh wave analysis program used for analysis of surface wave radiation patterns. A program to plot focal mechanisms on a Tektronix plotter was written and used. Also estimated using the above data were rates of slip and convergance found by comparison of seismic moments calculated from surface wave magnitudes. Composite focal mechanisms using bulletin first motions were constructed when unable to obtain clear focal mechanisms for a set of earthquakes in a region.

Morphology and Tectonics of the Scotia Sea Region.

The Scotia Sea is situated to the south of the South American continent, between the Antarctic Peninsula and the Falkland Plateau (figure 1). The most prominant topographic feature of the area is the South Sandwich arc - trench. This is a 1000 kilometer long north - south arc, with a 3 degree radius of curvature (only the Banda and Hellenic arcs have a smaller radius of curvature) (Tovisch and Schubert, 1978). The attendent trench descends to more than 8 kilometers below sea level(Frolova, et al.,1974).

The South Sandwich arc is a young feature which has existed in its current geometry for only 7 million years (Hill and Barker, 1980). Behind the arc is an active 'back arc' spreading center. This spreading center also stretches 1000 kilometers north - south, and lies on a broad bathymetric high 600 kilometers west of the arc. The back arc spreading center has been active for the past 7 million years, and is spreading with a 4 cm./year half rate between the latitudes of 55S and 60S (Barker, 1972; Hill and Barker, 1980) (figure 2).

The south margin of the Scotia Sea is the South Scotia Ridge, a jumbled series of blocks that rise from the abyssal depths to near sea level. From dredges, the easternmost

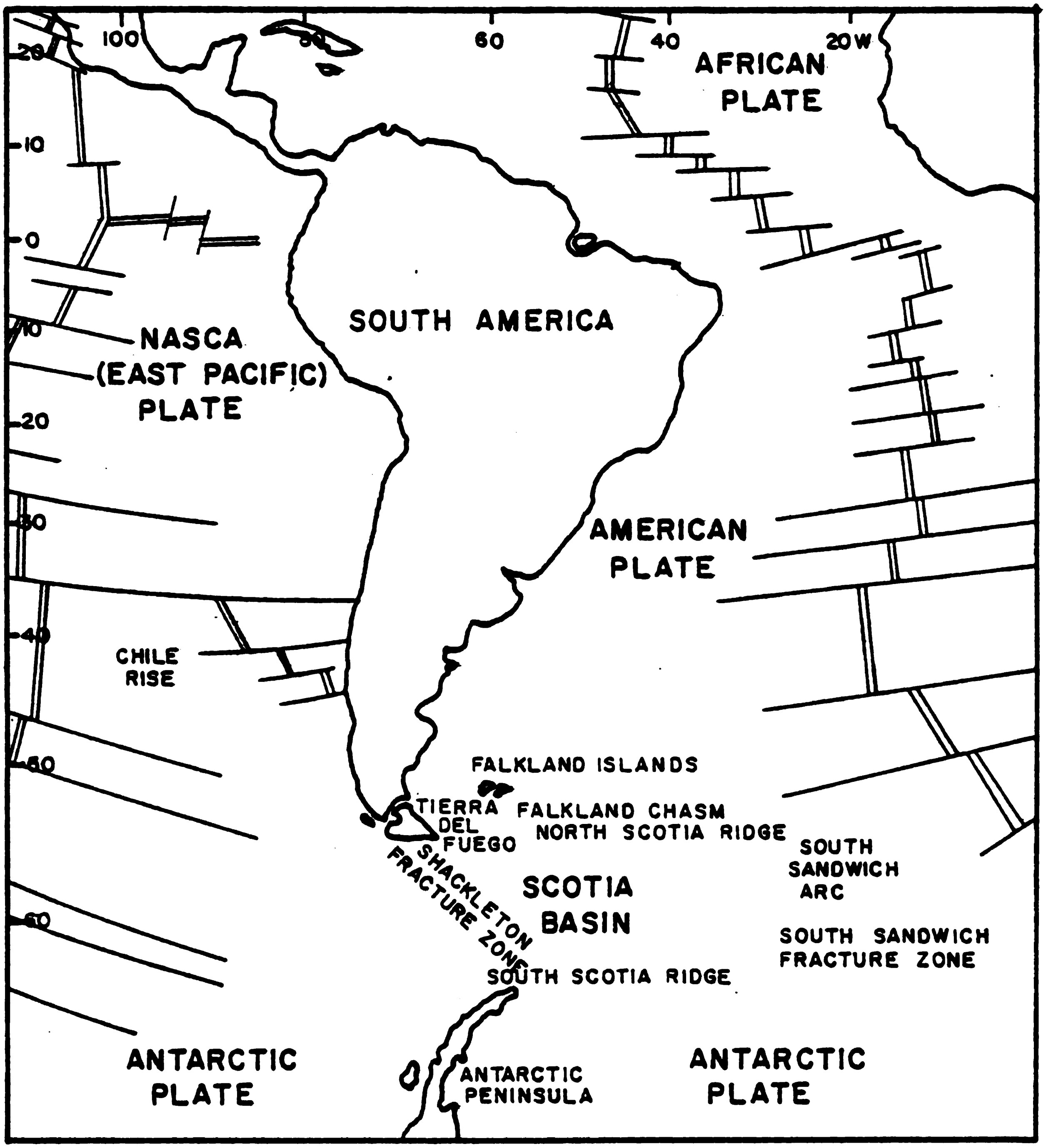


Figure 1 - South Atlantic Ocean

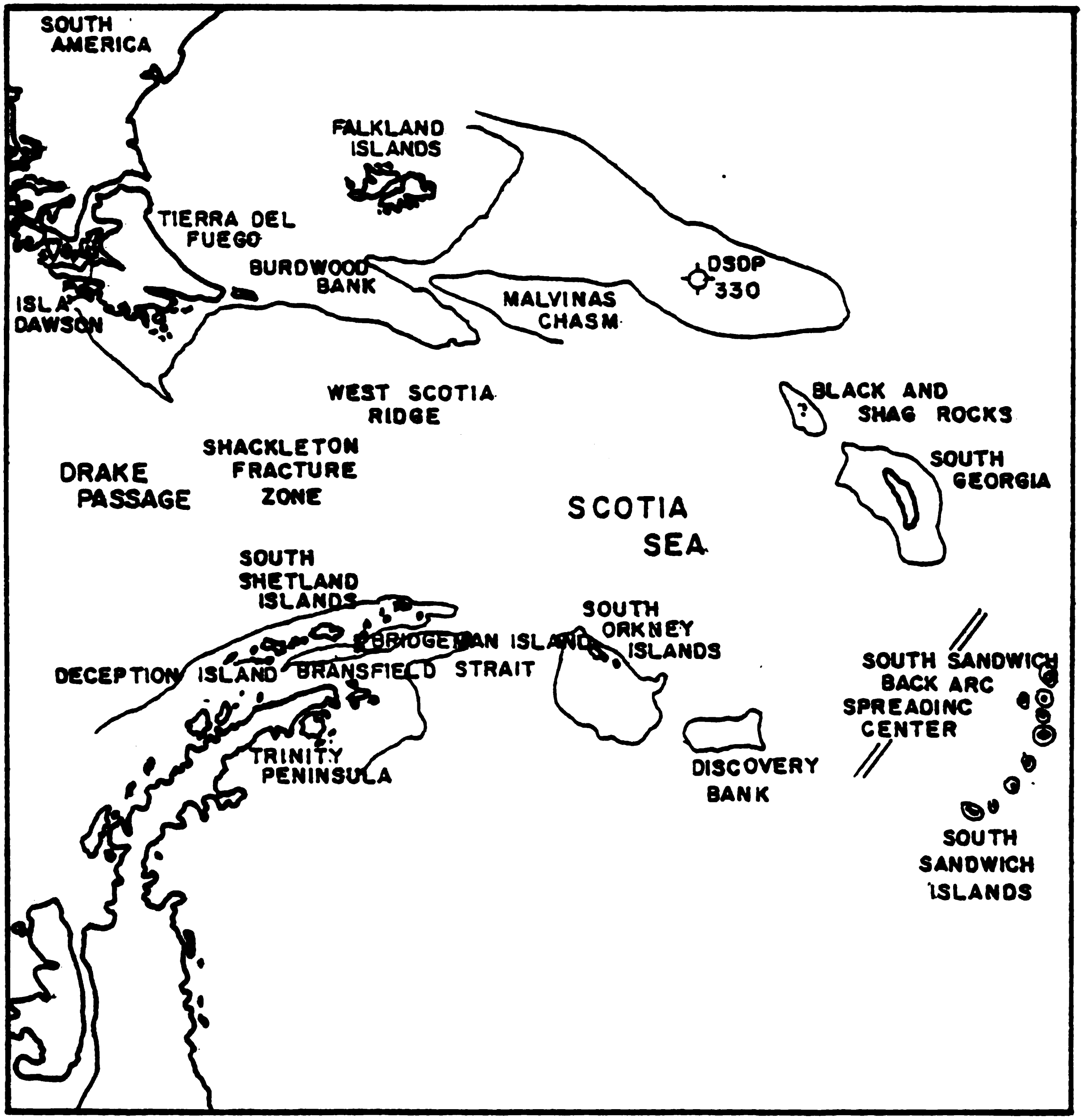


Figure 2 - Scotia Sea

block, Discovery Bank, is thought to be a remnant of a recent interoceanic island arc, active until 7 million years ago, and sharing similar structure, function and petrology with the current volcanic islands of the South Sandwich arc (Hill and Barker, 1980). The western blocks of the South Scotia Ridge, including the South Orkney Islands, are continental in origin, and possess Cretaceous and Tertiary sediments and volcanic intrusives (Harrington, et al., 1972).

Starting just east of the intersection of the Shackleton fracture zone and the South Scotia Ridge, the South Scotia Ridge becomes double, and this configuration continues to the southwest into the Antarctic Peninsula. The north part of this ridge is called the South Shetland Islands, and they are separated from the south part, the Trinity Peninsula, by the Bransfield Strait, a narrow two kilometer deep trough (Davey, 1972). To the northwest of the South Shetland Islands is the South Shetland trench, a five kilometer deep trench that stretches between the Shackleton fracture zone and the Hero fracture zone to the south.

The tectonics of these last features is debatable. The South Shetland Islands are known to be a recent island arc like feature (Griffiths and Barker, 1972), and the Bransfield Strait to be a downdropped block, with several active volcanic islands along its northwest edge. On the other hand, the Trinity Peninsula is of older continental origin (Davey, 1972). The tectonic activity of the Bransfield Strait, and the adjascent volcanic activity in the South Shetland Islands has been continual since the Miocene (Griffiths and Barker, 1972), however, historic volcanic activity is noted only for the Bransfield Strait volcanoes and not the South Shetland Islands (Simkin, 1981). These features are interpreted as either showing an active subduction zone (Hill and Barker, 1980, Griffiths and Barker, 1972) or a presently inactive subduction zone still undergoing back arc extension (Forsyth, 1975).

Seismic investigation of the Bransfield Strait show it to be a rift structure underlain with sediments and recent volcanics (Davey, 1972). In the trough are a line of bathymetric highs, probably volcanic vents (Griffiths and Barker, 1972), and this is the main evidence used to suggest it to be a recent structure associated with backarc extension.

To the northwest of this area is the Drake Passage, divided northwest - southeast by the Shackleton fracture zone. Extending from the Shackleton northeast into the Scotia Sea Basin is the West Scotia Ridge, a low inactive spreading center (figure 2). Magnetic lineations have placed the dates of activity of the West Scotia Ridge from Pliocene to Miocene (Hill and Barker, 1980). A continuation of this spreading ridge has been suggested to the southwest of the Shackleton fracture zone by Barker and Griffiths (1972). This spreading ridge has been hypothesized to be active to this day (Forsyth, 1975, fig. 2; Hill and Barker, 1980), although this is unsupported by magnetic lineations in the area (Okal, 1981; Hill and Barker, 1980). This spreading ridge henceforth will be called the Aluk Ridge.

The platelet to the east of the Aluk Ridge is called the Aluk plate (Herron and Tucholke, 1976) or the Drake plate (Herron, et al., 1977). The Aluk Ridge was active north of the Hero fracture zone from anomaly 6 time (20 million years ago) to anomaly 3 time (5 million years ago), and was active south of the Hero fracture zone from anomaly 29 to at least anomoay 5 time (10 million years ago) (Weissel, et al.,1977), with active subduction of the Aluk plate along the entirity of the Antarctic Peninsula until Eocene time (Craddock and Hollister, 1976).

At the north end of the Shackleton fracture zone is the South American continent. The southern tip of South America is also the scene of subduction to the east of the Aluk and Farralon plates in the Cenozoic (Herron and Tucholke, 1976), although the trench is buried under recent sediments and its present activity is uncertain (Herron et al., 1977).

The north boundary of the Scotia Sea from the west to

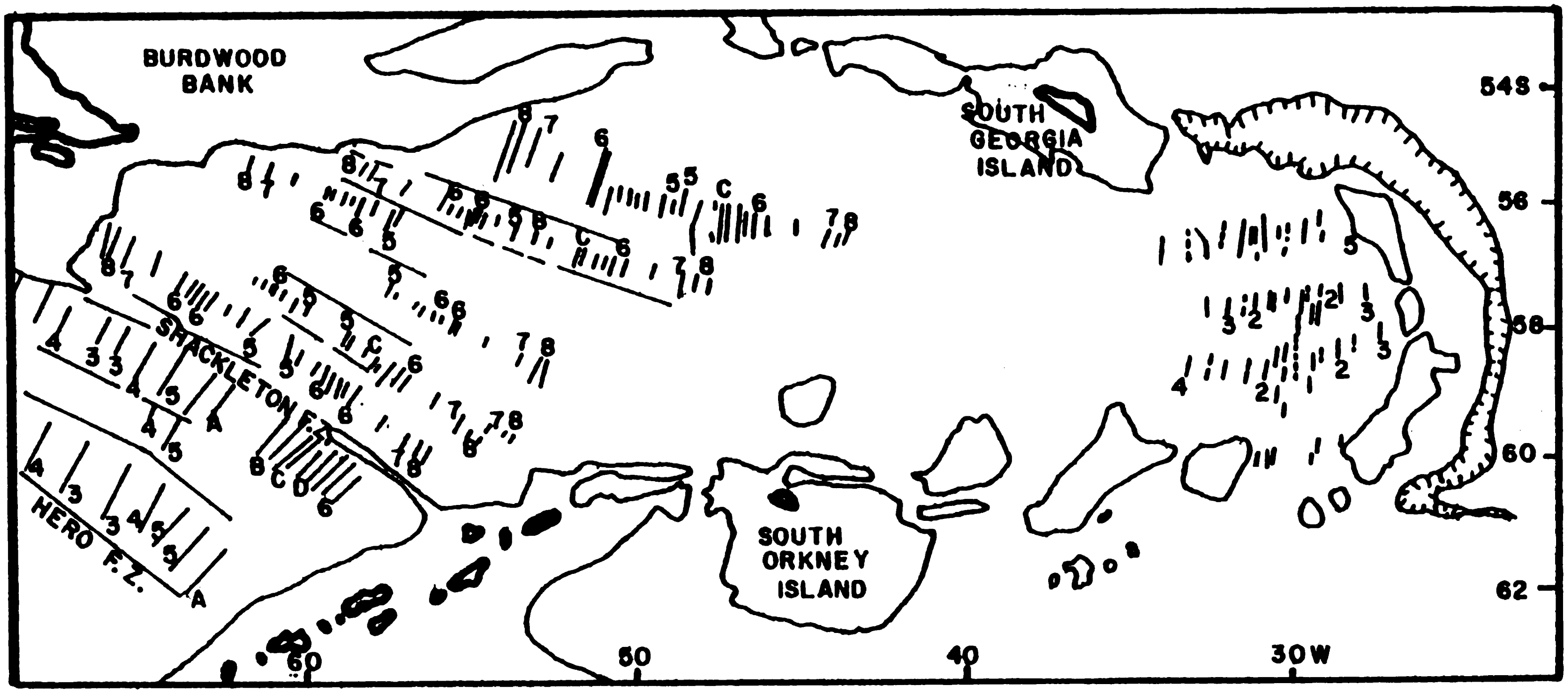


Figure 3 - Magnetic Lineations in the Scotia Sea

the east is composed of Tierra del Fuego, Burdwood Bank, North Scotia Ridge and South Georgia Island. South Georgia Island, and by extrapolation the North Scotia Ridge and Burdwood Bank, is known to consist of Cretaceous volcanics and sedimentary rocks (Brune and Dalziel, 1977). From its structure South Georgia Island is inferred to be a piece of the Andean cordillera similar to that of southern Chile, and to have moved to their present position from just south of the Burdwood bank sometime in the Cenozoic (Brune and Dalziel, 1977). The precise composition and origin of the North Scotia Ridge is not known, but the Falkland Plateau, separated from the North Scotia Ridge by the narrow Malvinas Chasm, is known to consist of sediments undisturbed by tectonic action since before the Cretaceous, lying on a continental Precambrian basement (Harris and Sliter, 1976). This continental basement is confirmed by drilling as far east as 46W 51S (Barker, 1976). The basement rocks were dated at 533 MY (Cambrian), using the SR 87/86 method, and they are intruded by pegmatites by 280 MY (K/Ar) (Beckingsale, et al.,1976).

The Scotia Sea itself is composed of oceanic crust, subdivided into western, central and eastern sections, each possessing an extinct or presently active spreading ridge (figure 3). The western section is the West Scotia Ridge commented on above, and is an inactive spreading zone. It was active 21 MY to 6 MY ago and spread roughly east - west (Barker and Burrell, 1977). The center section contains another inactive spreading ridge, also active until 7 million years ago (Hill and Barker, 1980). This ridge was situated roughly east - west and spread north - south. The eastern section is the presently active South Sandwich back arc spreading center, and it is spreading east - west. More than 70% of the ocean crust in the Scotia Sea has been dated by magnetic lineations, all younger than 30 million years old, and it seems unlikely that any of it will be found to be appreciably older (Hill and Barker, 1980).

The pole of relative motion between South America-Antarctica is located at 80N 14E, motion of .24 deg./MY by Forsyth (1975), and at 87.69N 75.20E, motion of .302 deg./MY by Minster and Jordan (1978). The above relative motions and plate boundaries as given by Forsyth (1975) are summarized in figure 4.

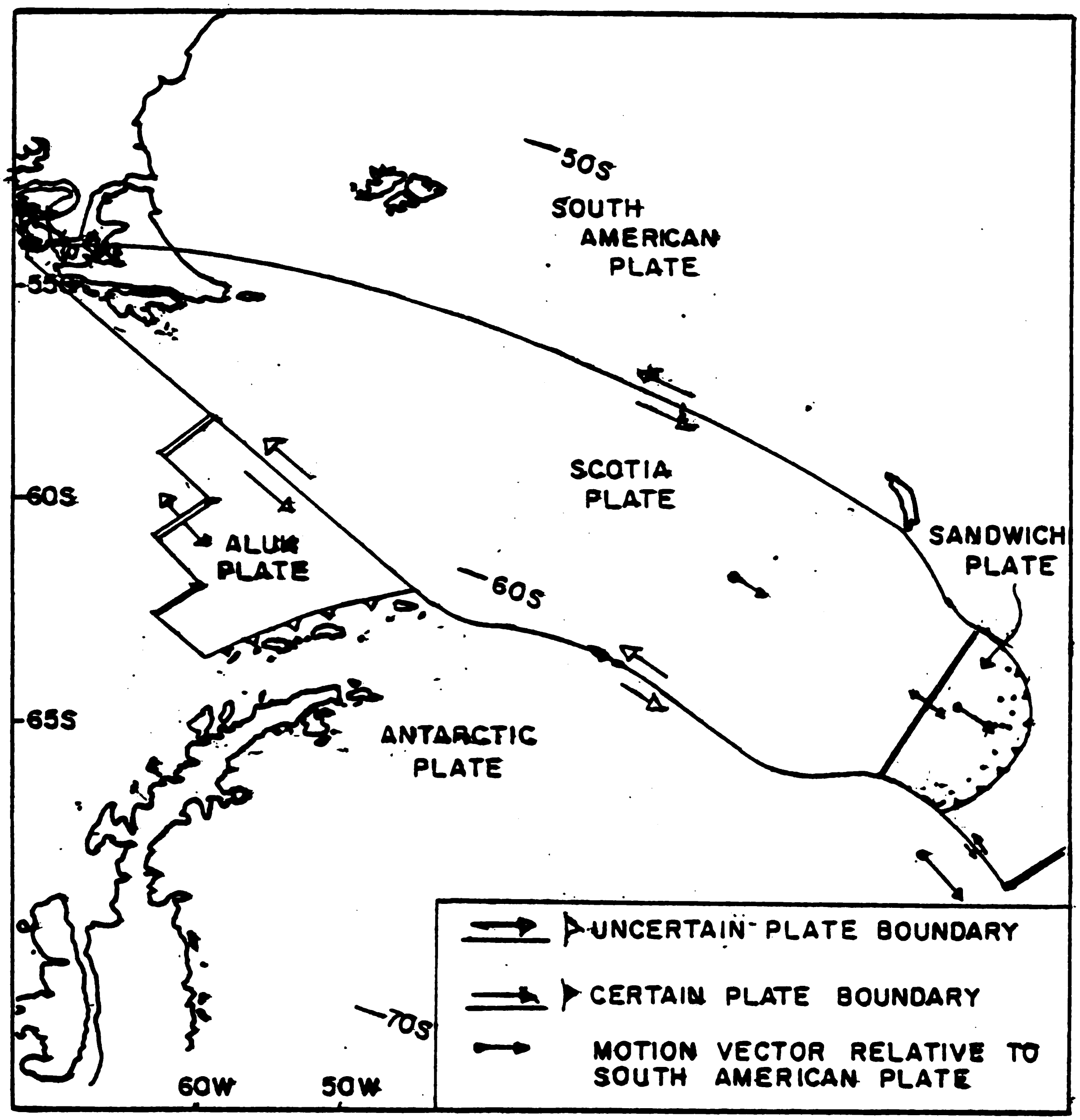


Figure 4 - Plate Motions in the Scotia Sea Area (Forsyth)

Previous Work on the Seismicity of the Scotia Sea

The most comprehensive study of the seismicity of the area is the Forsyth (1975) study which covered the South Atlantic, Scotia Sea and southernmost Chile. Extensive use of focal mechanisms determined from observed first motions and S wave polarizations were employed to support the directions and rates of relative motions along the various transform faults in the region (figure 4).

On the basis of the June 14, 1970 earthquake Forsyth (1975) constrained the motion along the North Scotia Ridge to be left-lateral strike-slip. Similarly, the Feb.25, 1973 earthquake was used to constrain the motion along the South Scotia Ridge to be left-lateral. No seismicity on the Shackleton fracture zone proper was observed - a bias caused by the short (1963 - 1973) sampling interval used - but the Shackleton was given as a left-lateral strike-slip boundary, constrined by a left-lateral strike-slip earthquake occuring where the Shackleton intersects the South Scotia Ridge (Forsyth, 1975). A seismically active region to the southwest of the Shackleton was represented by one focal mechanism for the earthquake on May 20, 1967, and it was called a thrust event on the basis of the ratio of the amplitudes of Love to Rayleigh waves seen at 5 stations.

Forsyth described this region as an area of intraplate compression, and in his figures showed a spreading ridge.

In the south Chile region two earthquakes were studied, Feb. 9, 1972 and June 14, 1970. Both focal mechanisms show left-lateral strike-slip motion. The Bransfield strait area was represented by the Feb. 8, 1971 earthquake, with a focal mechanism typical of normal faulting, and this was used to suggest an extensional nature for the Bransfield strait.

The main focus of Forsyth's study was on the South Sandwich arc - trench. Here 15 shallow and 12 intermediate depth earthquakes were studied. From these focal mechanisms came the observations that at intermediate depths downdip compression is predominant south of 58S, and downdip extension is predominant north of 58S. The north boundary of the arc was characterized by hinge faulting on a near vertical plane. Finally, 7 mechanisms were included for the connection between the arc and the Bouvet triple junction between the South American, African and Antarctic plates. These focal mechanisms indicated the proper left-lateral strike-slip motion expected on the transform faults associated with the South American - Antarctic spreading centers.

There have been two other general studies of the seismicity of the South Sandwich arc. Brett (1977) studied the lateral variations in seismicity, earthquake occurance and energy release along the arc. In his study he used a JED(Joint Epicenter Determination) multi - event epicenter location program to produce station corrections, later used to improve the locations of earthquakes within the Benioff zone. Specifically pointed out was the difference between the region to the north of 58S and to the south of 58S. A general decrease in dip of the Benioff zone going from north to south was observed, reflecting a general younging of ocean floor being subducted in that direction. The second study of the arc (Frankel and McCann, 1979) focused on the historical seismicity of the arc and nearby earthquakes to the east. Using a single event relocation program 35 historical earthquakes were relocated and error bars given for those with M > 7. This study showed that historically the seismicity of the north part of the subduction zone is higher than that of the south.

METHODOLOGY

Earthquake Relocation Methodology

Earthquakes were relocated with the use of a single event relocation program originally written by H. Kanamori and modified by K. Fujita, called HYP2DT. It was adapted for use on a DEC 11-23 microcomputer and modified for slightly faster running times. The program allows for the simultaneous solution of origin time, latitude, longitude and depth, gives RMS (Root Mean Squared) residual for the earthquakes, residuals at each station, and allows for the use of station corrections.

For earthquakes relocated in this thesis only the variables latitude, longitude (and the errors determined for each) were used. Origin time and depth are not well constrained by single epicenter relocation programs (Hales, 1981), but the epicentral location is well determined if for any distance range there are observations in all quadrants, and if there are no major lateral velocity inhomogeneities near source or reciever. The travel tables used in the program are those of Jeffries and Bullen and the P-wave arrival times used are those reported in the ISS, ISC, USGS bulletins or by personal observation read from WWSSN film chips. For older earthquakes (pre-1963) stations with large residuals were removed from consideration one at at time (largest first) until the RMS residual was under five seconds. For post-1963 earthquakes the large residual stations were removed until the residual was under 2.0 seconds. Also reflected in the relocation process is the fact that the threshold of event location for the Antarctic area was at M = 6 for pre 1958 earthquakes, and at M = 4.9 for post-1963 earthquakes, the change coming when the WWSSN network was set up (Okal, 1981). Thus there are far fewer pre-1963 earthquakes able to be studied than post-1963 earthquakes.

For the Drake Passage area, relocation was done for 23 events in the period 1964 - 1980 to test whether the scatter seen in epicenter location (between the Shackleton and Aluk Ridge earthquakes) was due to mislocation or to a real phenomenon. The earthquakes relocated were mixed between three groupings - Shackleton fracture zone area, Aluk Ridge area and Bransfield Strait area. To test to see whether station corrections made any difference in accuracy of location, the largest earthquake in the region as determied by the number of stations reporting, the Feb. 2, 1971 earthquake, was used as a master event. It had 123 stations reporting direct P-wave arrivals.

Using a test sample of 8 earthquakes, there was seen no appreciable advantage in using the source-station corrections based on the RMS residual computed. Also, the positional scatter of the epicenter locations (between the two methods) was random. The maximum difference in epicentral distance between a relocation using station corrections and an ISC location was 63.4 kilometers, and the minimum was 2.27 kilometers. More crucially, the epicentral scatter between relocations with station corrections and without station corrections ranged from 5 to 22 kilometers. These differences are smaller than the ISC epicenter to relocated epicenter distance half the time (see table 1). Thus with equal scatter among the three location methods any one is as good as the other. Also, as can be seen in figure 5, there is random angular scatter among those locations, tending to neither 'jump on to' or 'jump off of' bathymetric features. Therefore, relocation of modern epicenters in the Drake passage makes little difference, whether with or without station corrections. Historic events were relocated without the complication of station corrections, since, compared to the errors induced by near station or near earthquake velocity inhomogeneities, the errors induced by poor equipment dwarf all others, and station corrections are too small to matter.

The program itself progresses through five iterations, at each iteration reducing the RMS error by means of solving for the four variables (origin time, latitude, longitude and depth) at each station to obtain the smallest RMS error. Each iteration, approximations of error in each of the four variables are also computed and shown. After the fifth iteration the azimuth, distance and residual for each station are shown.

Table 1

Station Correction Usefullness Test

EVENT	DISTANCES(in kilometers)			RESIDUALS(in seconds)	
DATE M/D/Y	ISC vs.LOCATION USING STATION CORRECTION	ISC vs.LOCATION USING NO STATION CORRECTION	STATION CORRECTION LOC. vs. NO STATION CORRECTION LOC.	WITH STATION CORRECTION	WITH STATION CORRECTION
9/29/79	57.3	52.8	16.5	3.849	3.491
7/36/76	7.7	9.7	6.3	2.086	1.870
1/29/76	65.8	63.4	22.1	2.574	2.432
12/29/75 III	58.6	39.9	22.1	1.663	1.132
11/1/73	7.0	7.7	9.4	1.056	.999
10/3/69	11.6	6.7	18.0	1.905	1.916
6/7/69	8.6	7.1	12.5	1.081	.827
7/4/66	4.8	2.3	5.5	1.545	1.737

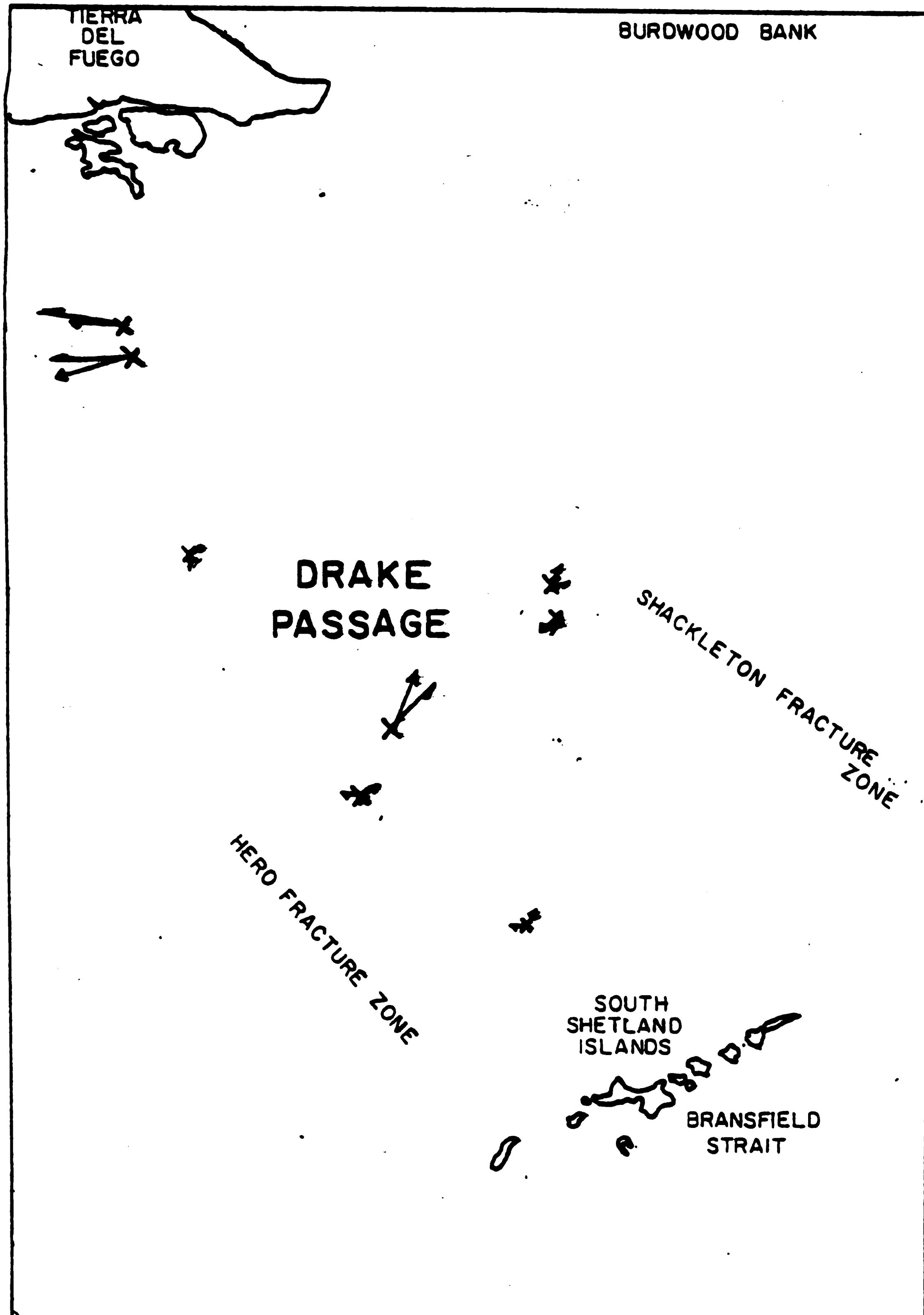


Figure 5 - Epicentral Scatter from Relocation

Rayleigh Wave Analysis Methodolgy

Rayleigh wave modeling was done for three eqrthquakes in the Drake Passage area, the main purpose to constrain further the focal parameters of strike, slip angle and dip angle.A slip angle of 0 degrees or 180 degrees is a pure strike-slip fault, and a slip angle of 90 degrees or 270 degrees is a pure dip-slip mechanism. Strike is the X axis orientation of the fault and dip angle is the angle the fault dips (Stein and Kroeger, 1980; Kanamori and Stewart, 1976).

To prepare the data the long period Z (vertical) component of each usable WWSSN (regardless of distance) film chip was photographed, Rayleigh wave arrival time marked and then digitized in a common format. R1 (direct Rayleigh path) was used for all cases, and R2 (antipodal Rayleigh path) was also used if visible.

The analysis was accomplished with a set of four programs written by S. Stein, and were used at Northwestern University and Michigan State University. The program took the FFT (Fast Fourier Transform) of each station record, and placed the data into the time - frequency domain. The data were equalized for distance and magnification of the station differences. The frequency data were then filtered by a cosine filter to remove unwanted short period frequency components (Kanamori and Stewart, 1976). This provides for an arbitrary amplitude plot of Rayleigh wave energy versus azimuth for the earthquake (Stein and Kroeger, 1980).

From this the seismic moment of the earthquake also can be calculated, and a synthetic Rayleigh wave pattern can be computed based on estimates of the strike, dip and slip (Kanamori, 1970; Kanamori and Stewart, 1976). A least squares match to the observed data can be computed for each possible radiation pattern. The possible radiation patterns are found by setting one of the three variables (strike, dip or slip) to a fixed figure, and letting the other two variables vary over all possible angles. From this and the given value for one of the variables the focal mechanism can be constrained.

Focal Mechanism Methodology

Focal mechanisms were constructed using a lower hemisphere polar equal-area projection. The data for each were taken from WWSSN film chips, when available, and when not, from the ISS, ISC or USGS bulletins. Dots and small crosses represent respectivley dilitations and compressions taken from bulletin picks, diamonds and large crosses represent either personal WWSSN picks or long period bulletin picks. Nodal planes were constrained by a visual best fit, reducing the number on inconsistant first motions to a minimum. If a nodal plane was not constrained by the data it was left out of the focal mechanism plots. For the precise focal mechanisms involved in this study see Appendix I.

Also used in analysis were composite focal mechanisms. A composite focal mechanism is constructed by plotting the first motions of several earthquakes as a single focal mechanism. The earthquakes combined in the composite plot have similar locations and depths, and are hypothesized to possess similar focal mechanisms. The composite focal mechanism plots were constructed in the method of Horiuchi et al. (1975), where the objective was a best fit solution that reduced the number of inconsistant first motions to a minimum. The Scotia Sea area was divided into 10 subregions to differentiate between different types of focal mechanisms. Each composite has also been graded, with the grade 'score' defined as:

$$Score = 100 * (1 - N_{inc} / N_{tot})$$

where N_{inc} is the number of inconsistant first motions, and N_{tot} is the number of total reported first motions (Horiuchi et al., 1975) (Table 2). A score of 85 indicates an average believability of data, as provided from the bulletins (Horiuchi, et al., 1975). For the precise focal mechanisisms involved in this study see Appendix II.

Table 2 - **Scotia Sea Area Composite Focal Mechanisms**

REGION NAME	"SCORE"	PLANE(S)
COM 1 Scotia Sea Back Arc Spreading Center	68	352/77
COM 2 North West Arc	71	40/88,310/86
COM 3 Outer Rise (North of 58S)	81	322/16
COM 4 Outer Rise (South of 58S)	78	192/80
COM 5 South America - Antarctic Spreading Center	74	170/80,260/80
COM 6 59.5S Fracture Zone	80	148/76,58/78
COM 7 Shackleton Fracture Zone	75	211/86,301/82
COM 8 Off Shackleton Area (Aluk Ridge)	85	195/80,285/84
COM 9 Bransfield Strait (1971)	76	30/90
COM 10 Bransfield Strait (1975)	75	35/78
COM 11 North Scotia Sea (Best fit strike-slip)	79	205/72,295/76
(Best fit dip-slip)	66	310/81

SEISMICITY

Bransfield Strait and South Shetland Trench

Recent seismicity (1964 - 1979) in the area is confined to two groups of earthquakes in the Bransfield Strait, the northern at 62S, 56.5W, and the southern at 63.5S, 61W. The northern group is located approximately in the center of the Bransfield Strait, on Bridgeman Island, while the the southern one centers on Deception Island. Both islands are volcanic (Dalziel, 1977; Tarney et al., 1975). Deception Island is an active volcano, with observed recent eruptions in 1956, 1967, 1970 and 1972 (Simkin, et al., 1981). Bridgeman Island, however, while given to be fumarolic, has no historically observed eruptions (Simkin, et al., 1981). However, few submarine volcanic eruptions are known of and cataloged (Simkin, et al., 1981), and since the bathymetry of the Bransfield Strait shows many submarine vents that could be presently active (Griffiths and Barker, 1972) thus it can be hypothesized that the seismicity is the result of volcanism.

These volcanoes are termed 'mildly alkaline' (Bridgeman) and 'calc-alkaline' (Deception) by Tarney (1977) and do not have the MORB chemistry usually associated with back arc extension (Tarney, 1977). But it is also

Table 3 - BRANSFIELD STRAIT EARTHQUAKES
ZONE CONFINED TO THIS POLYGON: 61.5S 54W-
64S 54W - 64S 63W - 61.5S 62W -
61.5S 54W.
(N MEANS BRIDGEMAN ISLAND CLUSTER, S
MEANS DECEPTION ISLAND CLUSTER)

	#	YR	MO	DY	TIME	LAT.	LON.	DHP	MAG	#STA.	#P	#FM	FOC.MEC.
B	1N	67	9	3	90922.	61.4	56.1	64	4.9	19	15	3	
B	2S	67	12	4	190022.	62.8	60.8	33	4.7	12	9	0	
B	3S	67	12	4	194838.	62.7	60.9	0	4.6	5	5	0	
B	4S	67	12	4	202831.	63.2	60.4	33	4.4	6	6	0	
B	5N	68	8	9	212624.	61.6	58.2	33	4.4	20	13	2	
B	6S	68	9	17	204727.	63.0	60.7	33	4.7	21	18	2	
B	7S	69	2	21	63224.	62.8	60.3	23	4.9	36	21	7	
B	8S	70	8	12	174206.	63.1	60.8	9	0.0	11	9	1	
B	9S	70	8	14	34633.	63.2	61.8	0	4.6	9	8	0	
B	10S	70	8	14	105414.	62.8	60.4	59	4.5	0	10	1	
B	11S	70	8	14	230647.	62.9	60.6	45	4.9	21	16	4	
B	12S	70	8	15	10400.	63.0	61.0	0	0.0	7	7	4	
B	13S	70	8	15	115844.	63.0	61.1	27	4.7	16	13	1	
B	14S	70	8	17	52545.	62.8	60.5	43	4.8	19	13	2	
B	15S	70	8	19	11611.	63.0	61.6	45	4.5	12	12	0	
B	16S	71	2	8	203748.	63.4	61.7	22	5.1	108	49	9	
B	17S	71	2	8	210419.	63.4	61.4	12	6.0	345	133	29	FOR
B	18S	71	2	10	32025.	63.3	62.0	5	4.7	21	14	1	
B	19S	71	2	10	111254.	63.5	61.7	33	4.8	37	22	3	
B	20S	71	4	24	160905.	62.4	61.1	33	4.7	36	23	0	
B	21S	71	5	7	80454.	63.4	61.9	9	4.6	14	9	1	
B	22S	73	2	16	92152.	63.4	62.2	29	4.8	55	31	7	
B	23S	74	3	14	84657.	62.8	61.1	33	4.6	8	8	3	
B	24S	74	3	15	80718.	62.9	60.6	33	0.0	10	8	0	
B	25S	74	3	15	180121.	62.8	61.1	33	4.6	15	11	2	
B	26S	74	3	15	230922.	62.7	61.1	33	0.0	9	8	2	
B	27S	74	3	16	192907.	62.9	60.5	33	4.7	21	17	4	
B	28S	74	3	16	220914.	62.8	60.4	33	4.9	12	9	3	
B	29S	74	3	17	23720.	62.9	60.5	33	4.7	23	18	4	
B	30N	75	1	15	10258.	62.1	58.6	33	4.6	19	17	2	
B	31N	75	1	15	44048.	62.1	58.6	33	0.0	7	7	0	
B	32N	75	1	15	214025.	61.6	57.0	33	0.0	9	8	2	
B	33N	75	1	15	225420.	61.9	55.9	187	4.5	28	20	2	
B	34N	75	1	17	113535.	61.9	55.2	33	4.8	13	11	0	
B	35N	75	1	19	21137.	62.2	56.4	33	4.6	14	12	3	
B	36N	75	1	24	12632.	61.8	58.1	33	4.8	15	10	3	
B	37N	75	1	26	172840.	62.1	56.2	18	4.7	19	16	2	
B	38N	75	1	27	142224.	62.1	56.1	15	4.8	32	27	3	
B	39N	75	1	27	183719.	62.0	56.1	27	5.3	90	46	6	
B	40N	75	1	31	131735.	62.0	56.1	33	4.8	21	15	1	
B	41N	75	2	4	141950.	62.2	56.9	33	4.6	13	11	1	
B	42N	75	2	10	2340.	62.2	55.5	33	4.7	9	8	2	
B	43N	75	2	15	145011.	62.2	56.2	32	5.0	33	24	4	
B	44N	75	2	26	153526.	62.3	56.9	33	0.0	11	10	1	
B	45N	75	3	4	211433.	62.0	56.5	33	0.0	8	8	0	
B	46N	75	3	9	210511.	62.2	56.4	33	4.9	15	13	2	
B	47N	75	3	11	80355.	62.4	56.7	45	4.8	8	7	2	
B	48N	75	4	18	182728.	62.0	56.7	33	5.3	19	14	2	
B	49N	75	4	25	4433.	62.0	56.3	33	5.1	43	28	5	
B	50N	75	5	1	145721.	62.1	56.1	33	4.8	44	29	2	
B	51N	75	6	2	212704.	62.0	56.6	33	5.1	15	13	3	
B	52N	75	6	4	60128.	62.0	56.9	48	4.7	21	15	0	
B	53N	75	6	9	21930.	61.6	57.1	33	5.1	14	12	1	
B	54N	80	9	15	42809.	61.5	56.6	10	5.8	80	?	?	

observed that the Rb/Sr ratios are lower and the K/Rb and Ba/Rb ratios are higher in the volcanics than in the 'subducting' oceanic crust. Thus these magmas are precluded from being derived from the subducted oceanic crust and can be classified as transitional between calc-alkaline and MORB composition (Tarney, 1977).

Furthermore, the seismicity is limited in time - no large historic seismicity is observed in the area in the period 1900 - 1960 (Gutenburg and Richter, 1954; Rothe, 1969), and recent seismicity along these islands is confined to the period 1967 to 1975. In the period 1967 to 1974 there were two events in the north cluster and 27 in the south, while in the 1975 there were 24 events, all in the north (see table 3). Except for one anomalous event (B34), reported in the ISC bulletin as having a 167 kilometer depth (and relocated to a depth of 160 +-3 kilometers), all other events listed are 60 kilometers or shallower in depth. There is no observed Benioff zone associated with these earthquakes (figure 6), and thus there is no active seismic subduction occuring in this area.

Also, plotting of the residuals of the large (Mb = 6.0) Feb. 8, 1971 earthquake versus azimuth show little or no consistant variation as would be expected of an earthquake located above a descending slab (Sleep, 1973). This shows that either the slab is detached, or has come to

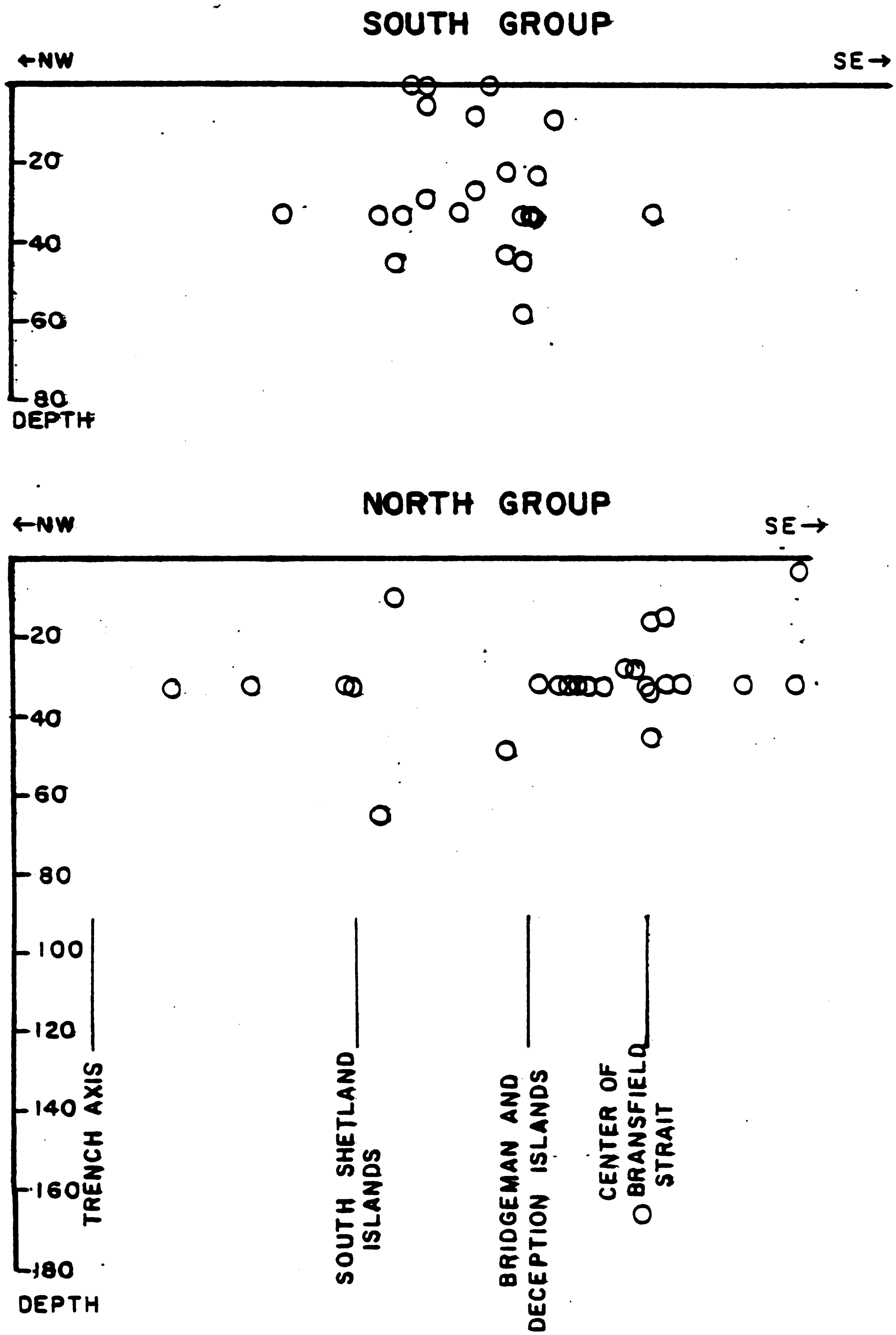


Figure 6 - Bransfield Strait Events Depth vs. Distance Plot

near equilibrium with surrounding mantle, again suggesting that subduction off this trench has not been active for some time, or has not been active very long.

Only one event was large enough to constrain a focal mechanism, occuring on Feb 8, 1971 in the south cluster, with a normal fault solution (Forsyth, 1975). In addition, construction of composite mechanisms show that normal faulting predominates in both clusters.

As the seismicity and the volcanism do not appear to be subducton related, and from petrological examination the volcanism is not typical of back arc spreading, another explanation must be sought.

The Drake Passage

The seismicity of the Drake Passage can be divided into two parts - seismicity located on the Shackleton fracture zone and seismicity in the Aluk Ridge area, to the southwest of the Shackleton. The two groups are close to each other, and are roughly parallel, averaging less than 100 kilometers apart. In recent (1963 - 1981) times there have been no earthquakes with an ISC reported Mb of 6.0 or larger, so the feature has both low seismicity, low magnitude and energy release earthquakes, making it hard to resolve at teleseismic distances into component parts (See Earthquake Relocation Methodology). Five of seven historic earthquakes relocated were located on the Shackleton, four of these having M of 6.0 or greater, and one M of 7 earthquake (see table 4 and figure 7).

To test to see if the Shackleton and Aluk Ridge earthquakes indicated multiple features, all modern and historic earthquakes were relocated via use of a single earthquake relocation program. When the relocations are plotted, the error bars of the epicenters plot such that two distinct groups can be seen, one on the Shackleton and the other to the southwest of the Shackleton (figure 7). Using a linear regression of the event locations, events on the Shackleton correlate to 98% with a straight line, which

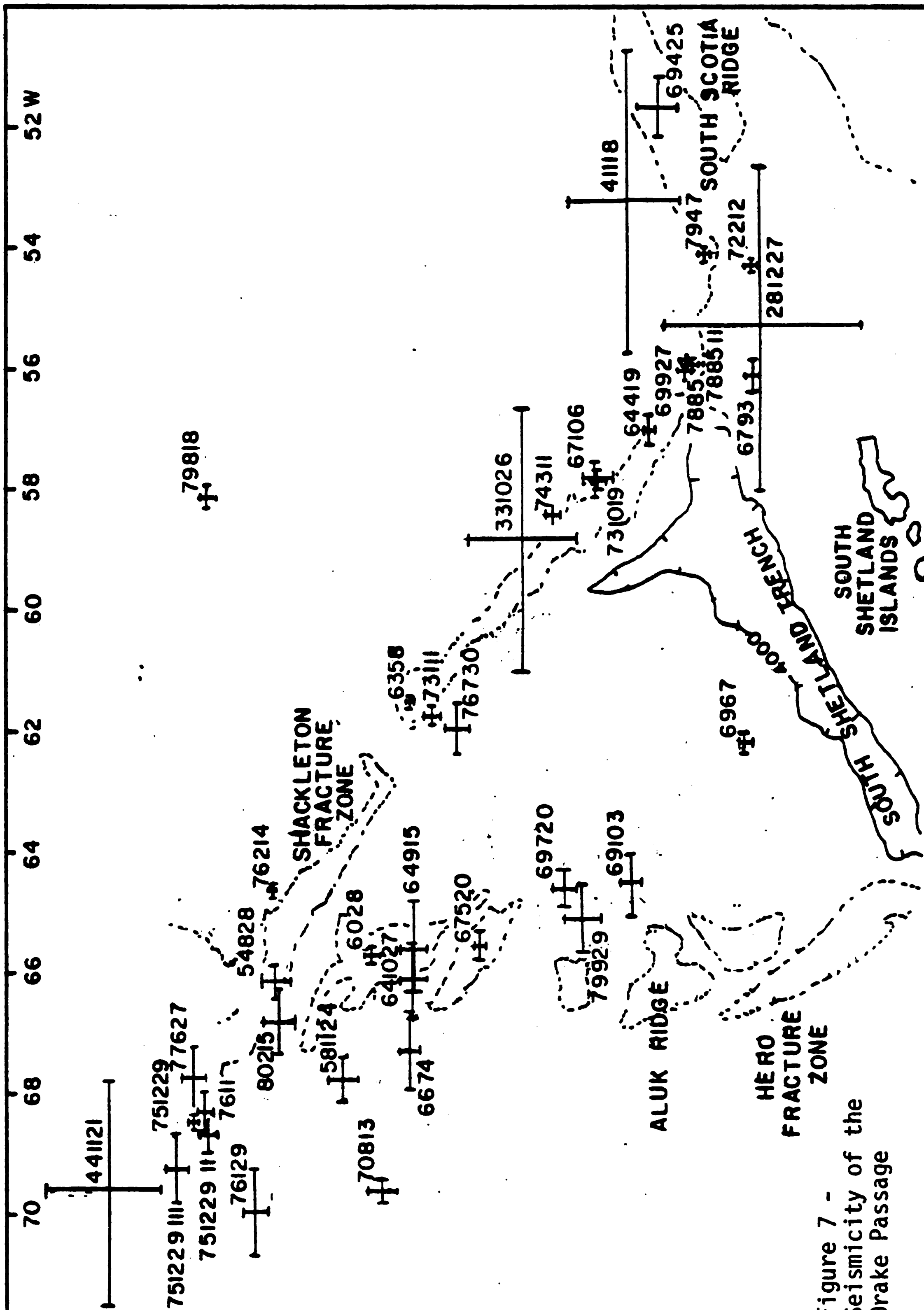


Figure 7 - Seismicity of the Drake Passage

Table 4 - SHACKLETON AND ALUK RIDGE EARTHQUAKES
ZONE CONFINED TO THIS POLYHEDRON: 56S 61W-
60S 55W-61S 62W-56S 70W-56S 61W (* MEANS RELOCATED)
(S MEANS ON SHACKLETON, A MEANS OFF
SHACKLETON IN GENERAL AREA OF ALUK RIDGE,
AND N MEANS NORTH EAST OF SHACKLETON.)

	#	YR	MO	DY	TIME	LAT.	LON.	DHP	MAG	#STA.	#P	#FM	ERROR(DEG)	FOC.MEC.?
A	1S	28	12	27	44610.	61.4	55.3*	10	6.2	27	5	0	.80,2.4	
A	2S	33	10	26	120702.	59.5	58.8*	10	6.7	77	13	0	.45,2.0	
A	3S	41	11	18	101436.	60.4	53.2*	10	7.0	72	11	0	.53,2.3	
A	4S	44	11	21	100220.	56.1	69.8*	50	6.5	26	9	0	.51,1.6	
A	5S	54	8	28	230424.	57.5	66.3*	10	0.0	63	26	5	.17,.49	
A	6A	58	11	24	64858.	58.1	67.9*	10	0.0	63	34	8	.12,.42	
A	7A	60	2	8	124534.	58.2	65.6*	10	0.0	165	66	17	.06,.20	
A	8S	64	4	19	141221.	60.5	57.0	33	5.3	105	41	7	.06,.26	YES
A	9A	64	9	15	210029.	58.6	65.8	2	5.0	22	17	20	.10,.97	
A	10A	64	10	27	223619.	58.5	65.9	33	5.2	59	33	13	.08,.36	YES
A	11A	66	7	4	357.	58.6	67.3	33	4.6	20	13	1	.08,.58	
A	12A	67	5	20	130210.	59.1	65.5	33	5.3	87	43	23	.06,.18	YES
A	13A	69	6	7	40301.	61.4	62.2	33	4.7	20	14	3	.04,.16	
A	14A	69	7	20	121345.	59.8	64.7	33	5.0	40	26	1	.66,.36	
A	15S	69	9	27	90404.	60.9	55.9	36	5.8	209	81	23	.36,.18	FOR
A	16A	69	10	3	83310.	60.4	64.7	33	4.7	13	11	2	.86,.50	
A	17A	70	8	13	85413.	58.4	69.2	33	4.8	15	11	5	.13,.18	
A	18S	72	2	12	25845.	61.8	54.4	33	4.6	11	10	2	.04,.12	
A	19S	73	10	19	134116.	60.1	57.9	33	4.8	25	20	5	.03,.11	
A	20S	73	11	1	195235.	58.8	61.9	33	4.7	17	17	2	.04,.17	
A	21S	74	3	11	53312.	59.6	58.4	33	5.3	63	31	11	.07,.16	YES
A	22S	75	12	29	33944.	56.8	68.4	18	5.9	292	96	33	.04,.13	YES
A	23S	75	12	29	45520.	56.7	68.3	33	4.9	16	10	3	.04,.05	
A	24S	75	12	29	93007.	56.8	68.5	36	5.1	87	42	7	.08,.27	YES
A	25S	76	1	1	34702.	56.9	68.1	42	0.0	8	8	1	.07,.34	
A	26S	76	1	29	120720.	56.9	68.2	33	5.1	15	10	2	.10,.67	
A	27S	76	2	14	31038.	57.4	64.5	40	5.9	249	88	26	.03,.09	YES
A	28S	76	7	30	321431.	59.0	61.8	33	5.0	37	10	7	.05,.29	
A	29S	76	10	6	40223.	60.1	58.0	35	4.7	15	14	3	.10,.23	
A	30S	77	6	27	65006.	56.9	67.9	29	5.0	18	15	1	.10,.52	
A	31S	78	8	5	64304.	60.8	55.9	4	5.6	179	80	17	.05,.29	YES
A	32S	78	8	5	82858.	60.9	56.0	23	4.8	28	21	2	.05,.47	
A	33S	79	4	7	81647.	61.1	54.3	10	4.7	120	6	2	.04,.12	
A	34N	79	8	18	181705.	56.9	58.1	33	5.1	41	37	10	.04,.12	
A	35A	79	9	29	50853.	59.9	64.3	33	4.9	16	15	4	.13,.54	
A	36S	80	2	5	135249.	57.4	66.3	10	5.2	26	20	6	.12,.43	
A	37S	81	1	18	30647.	61.1	55.3	10	6.0	57	?	?	? ?	

Table 5- Shackleton and Aluk Ridge Linearity of Earthquake Epicenters

NAME OF FEATURE	CONFIDENCE	START POINT	END POINT
Shackleton fracture zone	.98	61.33S 54.00W	56.49S 69.00W
Middle fracture	.84	60.54S 60.00W	57.38S 70.00W
South fracture	.97	62.03S 60.00W	58.10S 70.00W
All combined Aluk Ridge	.90	61.85S 60.00W	57.30S 70.00W
All Shackleton and Aluk Ridge	.85	61.34S 54.00W	57.13S 70.00W

follows the bathymetric expression of the Shackleton fracture zone almost exactly (Table 5). Combining the Shackleton data with the Aluk Ridge data yields a line that correlates with no topographic features. Possible linear trends were drawn for one and two Aluk Ridge features. The two feature solution yields lines that have correlation coefficients of 84% and 97%, but neither correlate well with bathymetry. The one feature system has a correlation coefficient of 90%, and plots roughly along an unnamed fracture zone to the southwest of the Shackleton.

Focal mechanisms for the Shackleton earthquakes show five distinct left-lateral focal mechanisms, and one right-lateral strike-slip mechanism. For the left-lateral events, the general strike is between 90 to 115 degrees, clustering around 110. Dip is within 15 degrees of 90 for all the left-lateral events, and slip angle is near 0. A composite mechanism of smaller magnitude Shackleton earthquakes yeilds almost identical data. Two earthquakes, Dec. 29, 1975 and Feb. 14, 1976, were studied in detail. Rayleigh wave modeling of these events corroborates the observed first motions as picked from WWSSN film chips (figures 8 and 9). The right-lateral mechanism earthquake, Aug. 5, 1978, occurs near where the Shackleton intersects the South Shetland Islands, and could represent a local small fault at right angles to the Shackleton's motion. Unfortunately, WWSSN

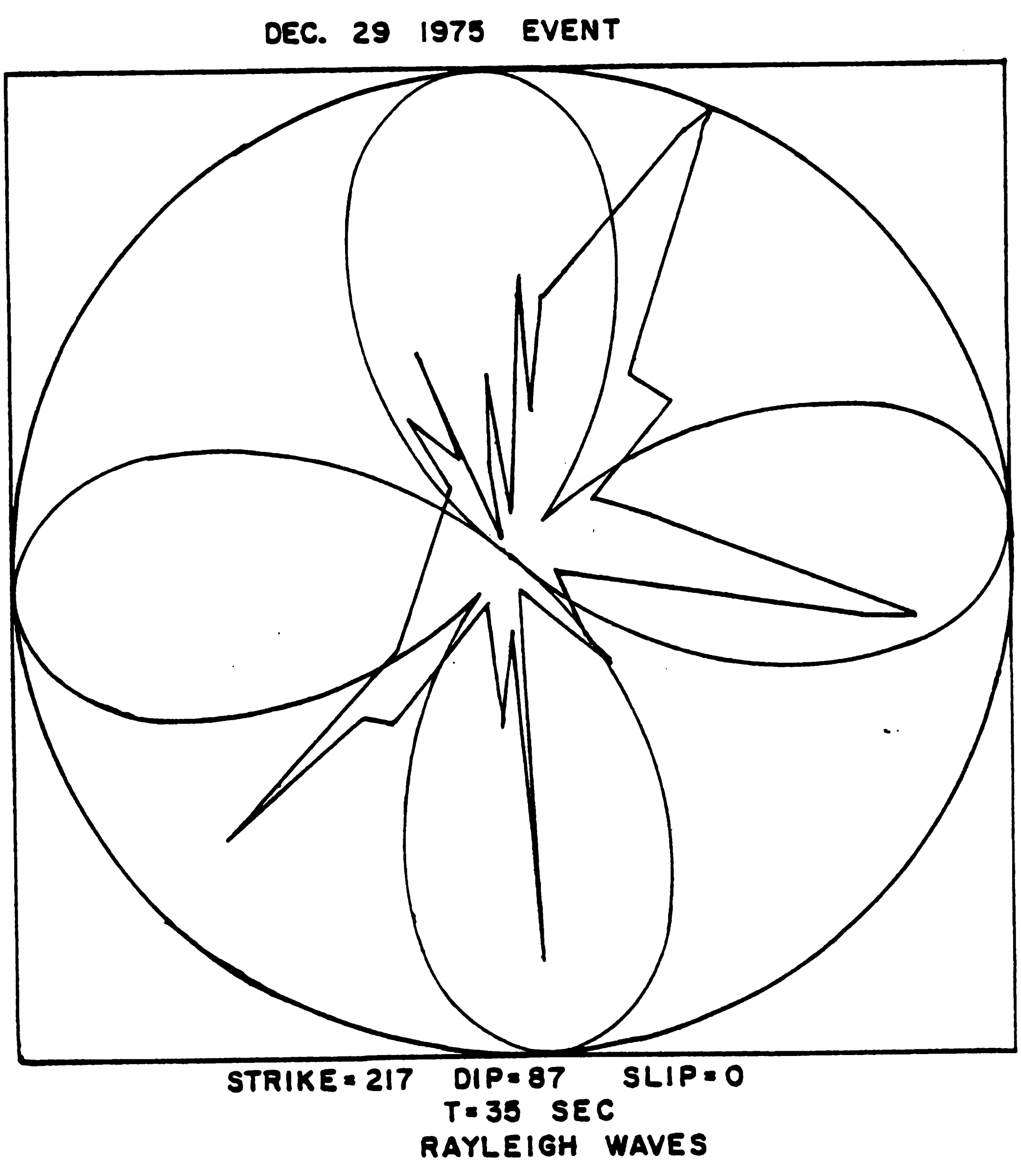
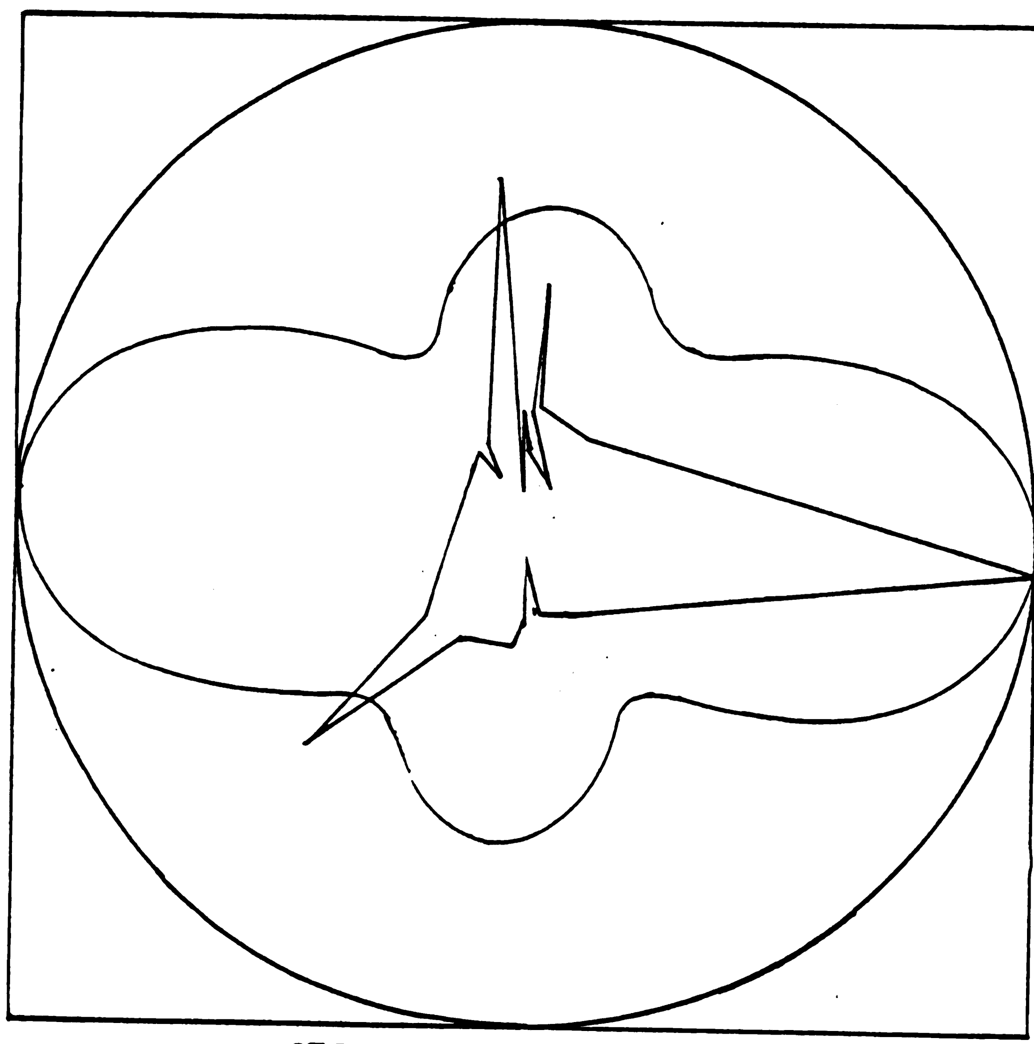


Figure 8 - Rayleigh Wave Amplitude Spectra of the 12/29/75 Event

FEB. 14 1976 EVENT



STRIKE=150 DIP=60 SLIP=40
T=35 SEC
RAYLEIGH WAVES

Figure 9 - Rayleigh Wave Amplitude Spectra of the 2/14/76 Event

records were unavailable for this event.

The Shackleton earthquakes show a higher rate of energy release than the Aluk Ridge earthquakes. The best evidence for this is that all the pre-1958 historic seismicity plots on the Shackleton. Also events observed in the Aluk Ridge area in the period 1963 - 1980 show consistantly lower magnitude and have fewer stations reporting. Only two focal mechanisms were obtained in the Aluk Ridge region; both are strike-slip mechanisms constrained using P-wave first motions picked from WWSSN records. The May 20, 1967 earthquake had previously been called a thrust event by Forsyth (1975). Rayleigh wave modeling at a 60 second period suggests that the earthquake is strike-slip (figure 10), as do bulletin PkP first motions. The other earthquake has only one constrained plane, and because of one reread first motion the second plane can be constrained, to make the mechanism left-lateral strike-slip.

Since no current spreading is mirrored in the magnetic lineations on the floor of the Drake Passage (figure 3; Hill and Barker, 1980; Okal, 1981) the strike-slip motion in the area southwest of the Shackleton cannot be directly related to spreading. Also, of the 9 earthquakes observed off of the Shackleton, four are off the supposed spreading axis, a quite high percentage, as the transforms not between the Ridge axis segments are usually seismically quiet. This

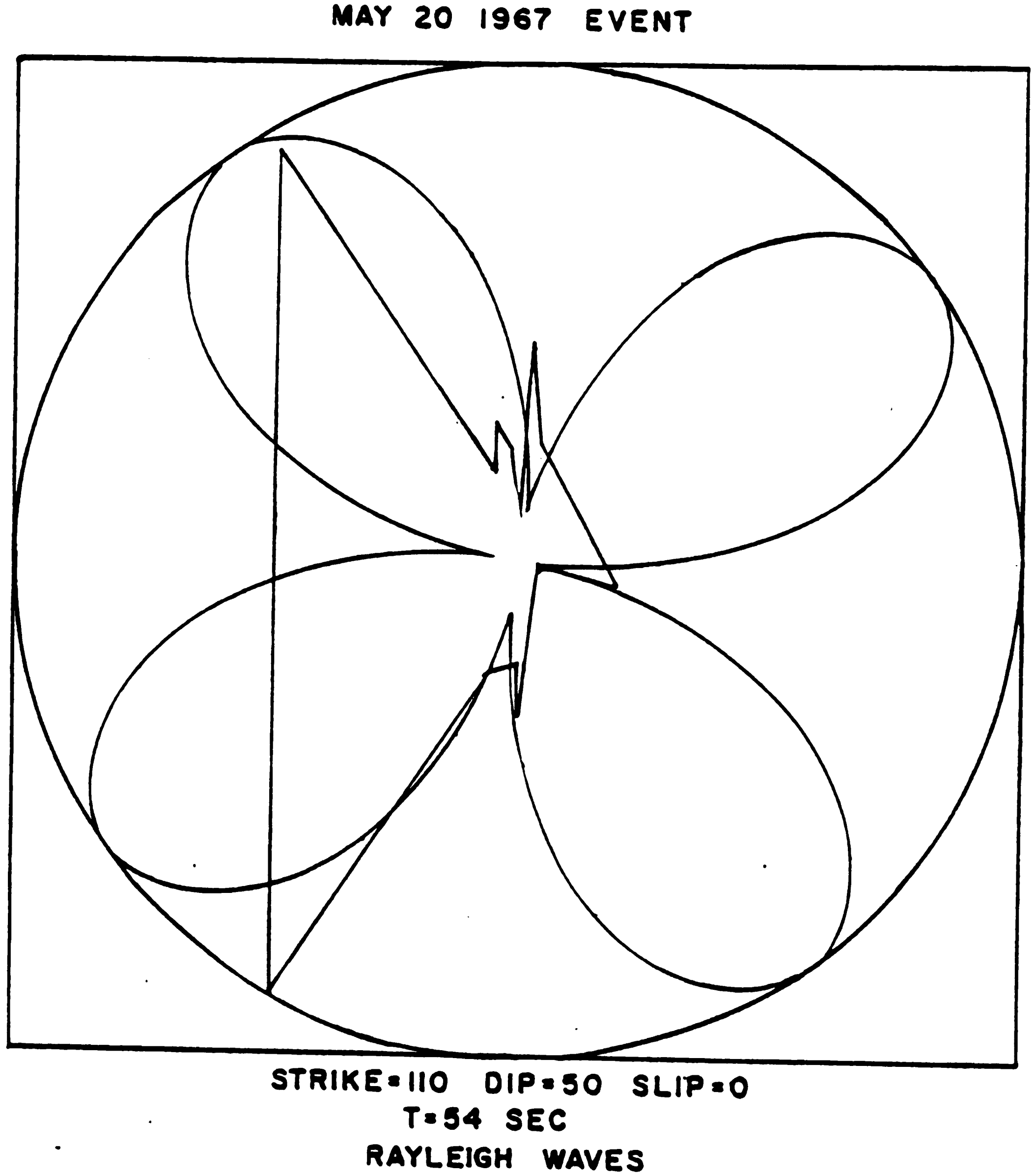


Figure 10 - Rayleigh Wave Amplitude Spectra of the 5/20/67 Event

strike-slip motion off the Shackleton can be related to another phenomenan, however.

The clustering of dates that was seen in the Bransfield Strait earthquakes can also be seen in the Drake Passage events. Using the same year clusters as for the Bransfield Strait earthquakes (1964 - 1974, 1974 - 1979), one sees this distribution:

1964 - 1974	1975 - 1979
9 off Shackleton	1 off Shackleton
5 on Shackleton	14 on Shackleton

The most distinctive year clusters for the on and off Shackleton earthquakes are 1964 - 1970 and 1972 - 1978:

1964 - 1970	1972 - 1979
8 off Shackleton	1 off Shackleton
1 on Shackleton	19 on Shackleton

This leads to the suggestion that seismic activity of the Drake Passage is related to the volcanism (seismic activity) of the Bransfield Strait. This would not be expected if the volcanism were independent of the activity of nearby plates (i.e., back arc spreading). What can be seen is that the time distribution of strike-slip events in the Drake Passage precedes the main seismic events in the proper cluster in the Bransfield strait: early Aluk Ridge earthquakes start around 1964, and earthquakes in the Bransfield Strait south cluster start in 1967, and Shackleton events start either in 1969 or 1972, and the Bransfield Strait north cluster earthquakes start in 1975.

A possible reason for these relations is the bend in the plate boundaries where the Shackleton intersects the South Scotia Ridge. At this point the direction of motion of the strike-slip faults turns by 60 to 90 degrees in 200 kilometers (based on the strike of the Sept. 29, 1973 earthquake versus the strike of the Shackleton fracture zone). If the Aluk Ridge zone of earthquakes is taken as a separate strike-slip boundary, then it also turns by a similar amount when it intersects the South Shetland Islands. This, plus the fact that very near the point of turning is a reverse direction (right-lateral) strike-slip event, shows that the area is a zone of deformation resulting from the bend of the strike-slip faults. A geometric consequence of this could be the imparting of tension on the block containing the South Shetland Islands, and presupposing that they already represented a zone of weakness, they could be being extending away from the Trinity peninsula, and thus driving the volcanism (figure 11).

The Aluk Ridge seismicity indicated represents a broad, diffuse feature, not well correlated with topographic features, in and around the area of an inactive spreading center. Motion as indicated by two earthquakes is parallel to the nearby Shackleton fracture zone. Its motion could also be the result of stresses accumulating because of the change of motion between the Shackleton and South Scotia Ridge.

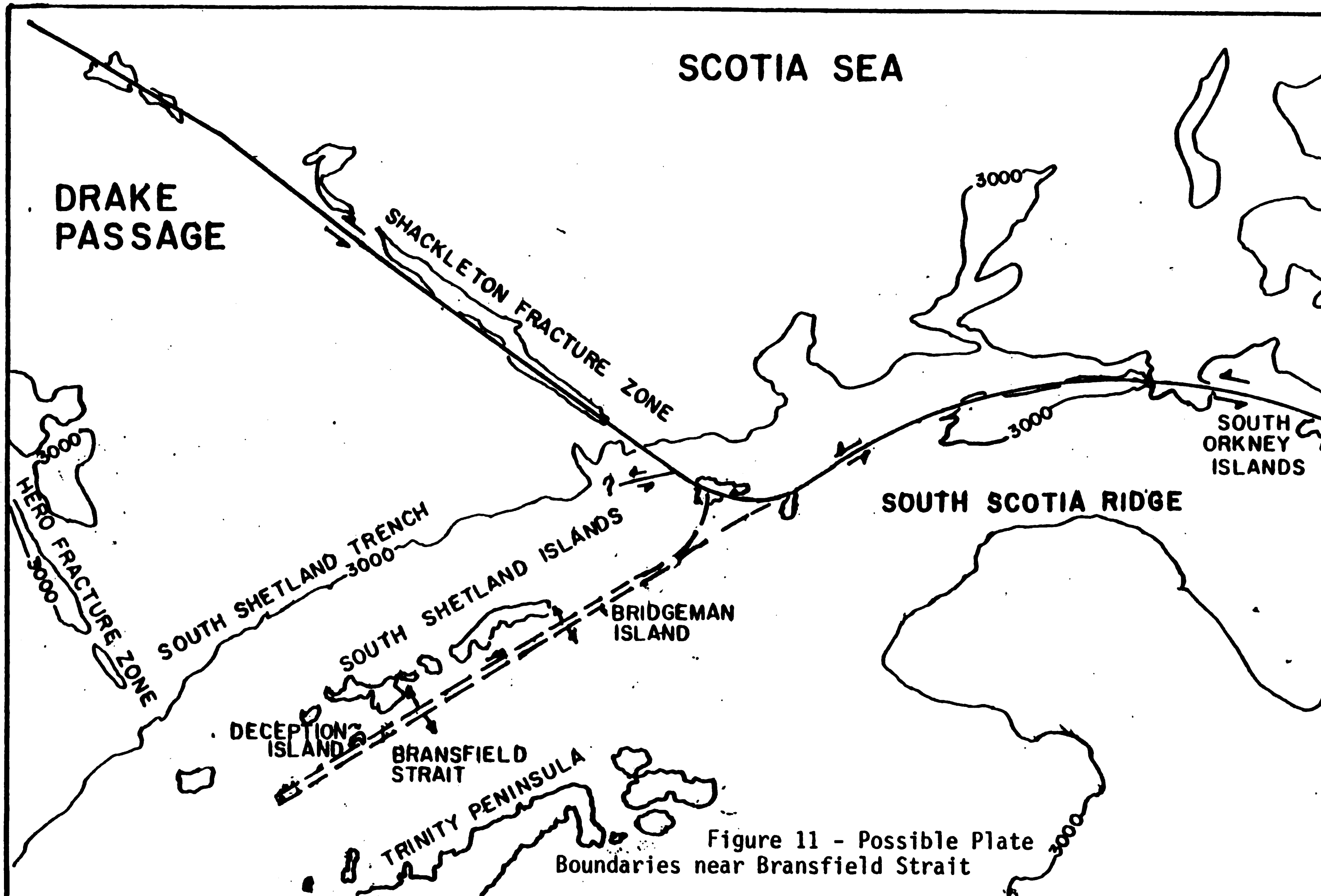


Figure 11 - Possible Plate Boundaries near Bransfield Strait

South Scotia Ridge

A zone of seismicity roughly along 61S follows the bathymetric trace of the South Scotia Ridge. The seismicity starts a few degrees east of the intersection of the Shackleton fracture zone and the South Scotia Ridge, at 52W, then tends east north east until 46W, where the South Scotia Ridge intersects the South Orkney Islands. There is a seismic quiet zone in the region of the South Orkney Islands, 250 kilometers wide, and the seismicity picks up again to the east on the other side of the Orkneys. To the east of the Orkneys, the region of seismicity trends east, then northeast to about 31W, where focal mechanisms show a change in seismicity to normal faulting. This is the location of the triple junction between this boundary, the South Sandwich back arc spreading center, and another transform boundary connecting the back arc spreading center and the subduction zone (figure 12; table 6).

The 6 focal mechanisms constructed in this region show strike-slip (left-lateral) mechanisms for five events and normal faulting in one (see above). The strike of these events tends from 70 degrees east of north in the west to 110 degrees east of north in the east, generally following the local strike of the South Scotia Ridge.

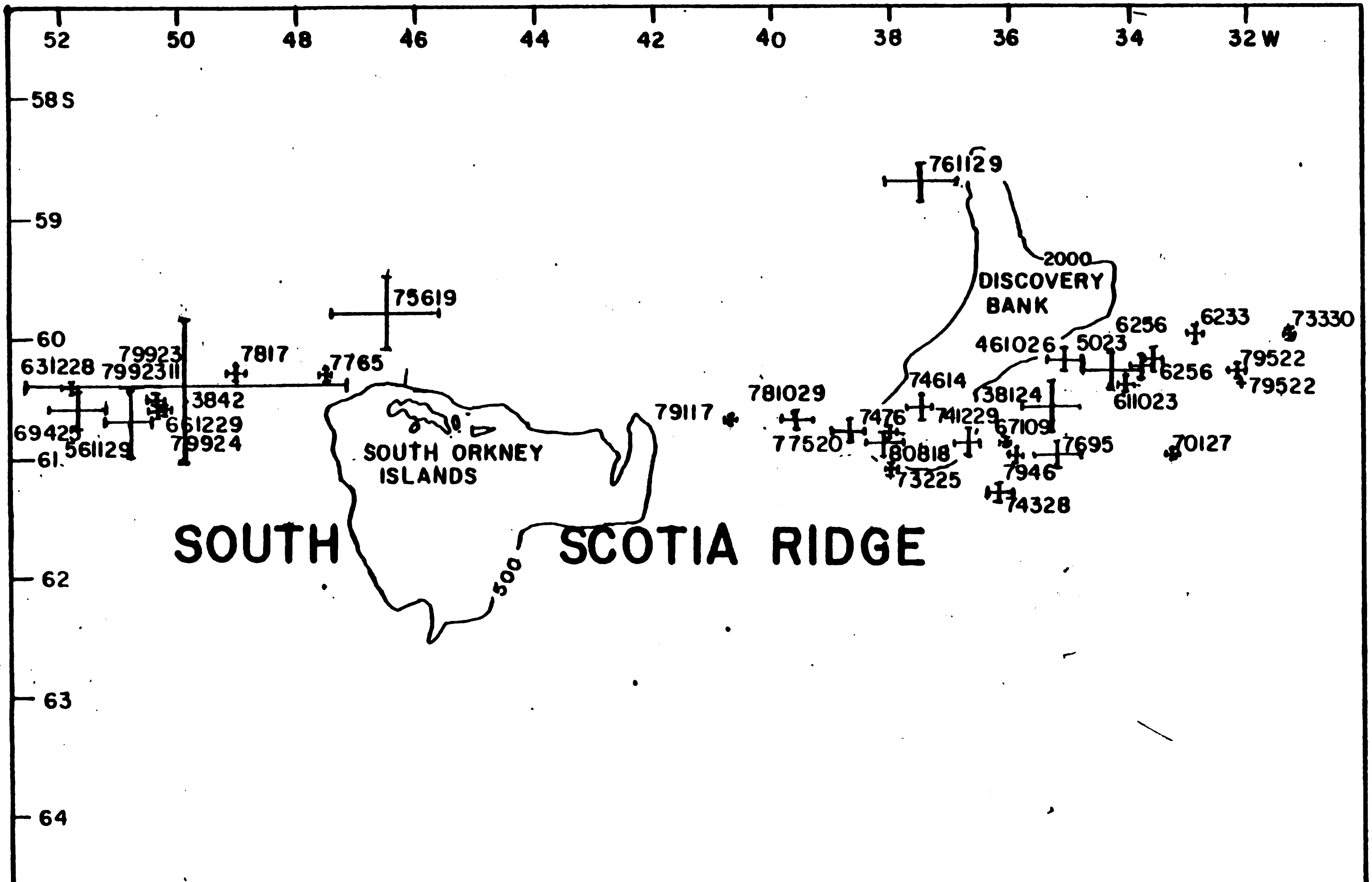


Figure 12 - Seismicity of South Scotia Ridge

Table 6 -

South Scotia ridge earthquakes:
Polygon from 58S 31W to 62S 31W to 62S 53W to 58S 53W
to 58S 31W.(* means relocated)

	#	YR	MO	DY	TIME	LAT.	LON.	DHP	MAG	#STA	#P	#FM	ERROR(DEG)	FOC.MEC?
S	1	38	1	24	103144.	60.8	35.3*	10	7.1	149	23	2	.20,.51	
S	2	38	4	2	60200.	60.2	49.9*	10	6.2	80	7	0	.40,2.8	
S	3	46	10	26	2103.	60.2	35.1*	10	7.0	69	14	2	.10,.29	
S	4	50	3	2	183945.	60.3	34.3*	10	6.9	100	22	5	.17,.27	
S	5	56	11	29	41333.	60.7	50.8*	10	0.0	52	24	7	.29,.41	
S	6	61	10	23	836.	60.4	34.1*	10	6.5	171	51	7	.08,.16	
S	7	62	5	3	33449.	60.0	32.9*	20	6.0	133	49	12	.07,.16	
S	8	62	5	6	190009.	60.2	33.6*	33	0.0	252	70	22	.08,.14	
S	9	62	5	6	215346.	60.2	33.8*	33	0.0	53	23	2	.10,.18	
S	10	63	12	28	175833.	60.4	51.7*	49	0.0	81	40	7	.05,.13	
S	11	66	12	29	231620.	60.8	50.3	33	5.2	38	26	9	.05,.11	
S	12	67	10	9	45510.	60.9	36.1	33	5.0	33	17	2	.04,.10	
S	13	69	4	25	210016.	60.6	51.7	33	4.4	18	13	1	.16,.45	
S	14	70	1	27	121901.	61.0	33.3	15	4.9	32	20	3	.04,.09	
S	15	73	2	25	53557.	61.1	38.0	41	6.2	223	82	35	.03,.07	FOR
S	16	73	3	30	34729.	60.0	31.3	75	5.4	141	67	33	.05,.09	yes
S	17	74	3	28	35917.	61.3	36.2	33	5.0	21	18	3	.07,.18	
S	18	74	6	14	132441.	60.6	37.5	28	5.4	126	51	10	.09,.19	
S	19	74	7	6	145123.	60.8	38.0	31	5.5	145	72	19	.05,.10	yes
S	20	74	12	9	212442.	60.9	36.7	33	5.1	44	33	6	.11,.19	
S	21	75	6	19	94552.	59.8	46.5	33	0.0	5	5	1	.30,.91	
S	22	76	9	5	145727.	61.0	35.2	33	4.9	15	9	2	.10,.40	
S	23	76	11	29	60735.	58.7	37.5	33	0.0	8	8	2	.14,.60	
S	24	77	5	20	112417.	60.7	38.7	33	4.9	17	7	3	.10,.27	
S	25	77	6	5	232610.	60.3	47.5	33	5.2	79	56	17	.03,.07	yes
S	26	78	1	7	33816.	60.3	49.0	3	5.2	44	23	5	.06,.12	
S	27	78	10	29	70135.	60.7	39.6	31	4.7	28	22	1	.06,.24	
S	28	79	1	26	173842.	60.3	50.5	0	4.8	8	5	1	.06,.25	
S	29	79	4	6	145407.	61.0	36.4	10	4.7	16	22	2	.05,.10	
S	30	79	5	22	92033.	60.3	31.8	10	4.8	30	11	3	.07,.15	
S	31	79	5	22	213827.	60.4	32.1	10	5.3	133	40	7	.03,.07	
S	32	79	9	23	224339.	60.6	50.2	10	5.9	175	64	28	.03,.07	yes
S	33	79	9	23	230325.	60.5	50.3	10	5.7	88	57	14	.03,.09	
S	34	79	9	24	64046.	60.6	50.3	10	5.6	67	46	16	.03,.09	yes
S	35	79	11	7	140352.	60.7	40.7	10	5.2	22	16	3	.03,.09	
S	36	80	8	18	63045.	60.9	38.1	10	4.7	10	8	3	.10,.27	
S	37	80	11	3	005152.	60.3	52.7	10	4.9	18	15	3	.27,.21	

South Chile and North Scotia Sea

Chile south of 50S has been thought to be an area of plate convergence. It is the location of a buried trench that has no currently active Benioff zone - it is aseismic (Forsyth, 1975; Herron, 1977). A large negative free air anomaly follows the trace of the buried trench and its attendent terraces, similar to the Aleutian terraces (Herron, 1977). At 54S a change in character of the observed gravity and magnetic anomalies occur, and the terraces pinch out to the north, suggesting a change in tectonics at 54S (Herron, 1977). The terraces are blocks of denser material separated from the continent by a basin filled with recent sediments, and it lies on line with the northern extension of the Shackleton (Herron, 1977). Regional stress in the area is oriented along a line 80 degrees east of north, as calculated from poles of rotation between the Antarctic and south American plates (Forsyth, 1975).

Recent and historic seismicity along the region from 50S to 54S has not been absent. In the period 1959 - 1980 there have been 6 earthquakes in the region with more than 130 stations reporting arrivals, with a maximum magnitude of 6.2. Three historic 7.0 magnitude earthquakes are known, two of which, at M = 7.7, occurred on the same day (Dec.17, 1949). Four focal mechanisms were constrainable, all of

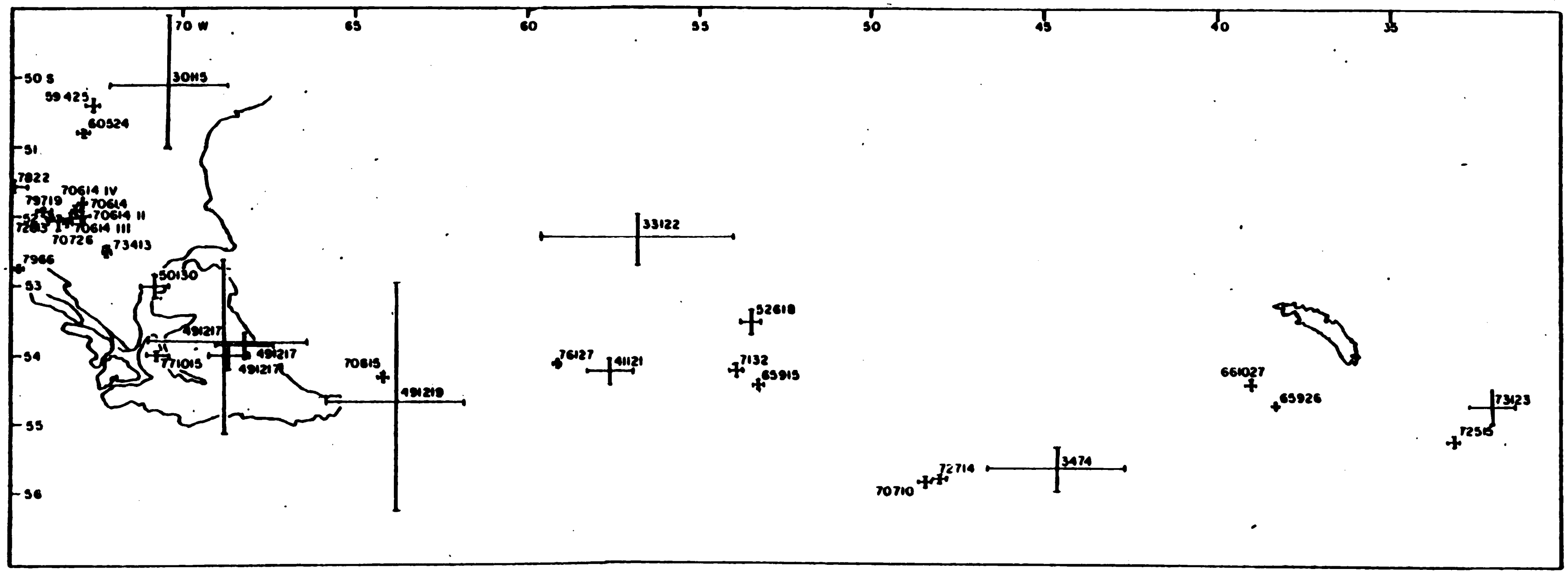


Figure 13 - Seismicity of South Chile and North Scotia Ridge

which have left-lateral strike-slip mechanisms, striking roughly parallel to the Chilean coast (table 7 and figure 13).

Although stress is oriented roughly east-west in the area (Minster and Jordan, 1978; Forsyth, 1975), no thrusting events are seen. The compression in the area is thus being taken up by strike-slip motion 45 degrees from the direction of stress, along the strike of the previously active subduction zone in the area.

The FFF triple junction surmized for Tierra del Fuego shows little seismicity (only 1 small event 1960 - 1980). There is a large free air anomaly at the point of intersection on Isla Dawson (Herron, 1977). A hypothesis to explain this area is that slow creep and thrusting is occurring on the continent, governed by the rate of motion of the north boundary of the Scotia plate, and over time the location of the zone of movement is changing on the continent. The south branch of this triple junction does not line up with the Shackleton, and there is a lack of seismicity from 54S to 56.5S (between Isla Dawson and the Shackleton Fracture zone) suggesting a broad zone of deformation between 54S and 56.5S, dominated by aseismic creep over many small faults.

The proposed north plate boundary of the Scotia plate is ill defined by seismicity, suggesting a broad belt of

Table 7-
Chile south west coast earthquakes
Polygon from 50S 70W to 54.5S 67W to
54.5S 75W to 50S 75W to 50S 72W.
(* means relocated.)

EQ#	YR	MO	DY	TIME	LAT.	LON.	DHP	MAG	#STA.	#P	#F.M.	ERROR(DEG)	FOC.MEC.?
C 1	30	7	13	11222.	50.1	70.4*	10	6.2	20	5	0	1.1,1.8	
C 2	49	12	17	065430.	53.8	68.2*	10	7.7	180	61	3	.19,.82	
C 3	49	12	17	125543.	53.8	68.7*	10	0.0	110	6	0	1.2,2.3	
C 4	49	12	17	150755.	54.0	68.7*	10	7.7	178	61	3	.18,.58	
C 5	50	1	30	005832.	53.0	70.8*	10	7.0	120	37	4	.14,.42	
C 6	59	4	28	114426.	50.4	72.6*	10	6.2	130	65	20	.05,.22	
C 7	60	5	24	203243.	50.8	72.9*	10	6.0	91	65	7	.06,.19	
C 8	70	6	14	000011.	52.0	73.8	33	6.0	296	128	31	.04,.09	For
C 9	70	6	14	001224.	52.1	74.3	23	5.4	74	42	6	.04,.10	
C 10	70	6	14	072312.	52.0	73.9	33	4.6	18	16	1	.06,.19	
C 11	70	6	14	200246.	52.0	74.2	33	4.7	17	13	1	.06,.23	
C 12	70	7	10	70004.	55.8	48.4	33	4.9	27	22	4	.06,.14	
C 13	70	7	26	150732.	52.1	74.6	33	4.9	14	14	2	.05,.30	
C 14	70	9	19	234148.	51.9	74.1	33	4.8	42	31	4	.05,.15	
C 15	72	2	9	204436.	51.8	74.0	33	5.7	177	95	25	.03,.07	
C 16	72	8	13	114752.	51.8	73.9	64	5.6	134	61	16	.03,.10	For
C 17	73	4	13	223639.	52.5	72.1	11	5.0	37	22	11	.03,.09	yes
C 18	77	10	15	141506.	54.0	70.7	33	4.8	12	11	1	.05,.28	
C 19	78	1	22	071140.	51.6	75.1	33	?.?	9	6	0	.10,.51	
C 20	79	6	6	105431.	52.7	74.7	62	5.5	122	62	17	.04,.11	yes
C 21	79	7	19	134410.	51.9	74.1	33	4.8	8	7	0	.06,.24	

Table 8 -

North boundary of the Scotia Sea earthquakes:
North boundary of the Scotia Sea zone
confined to this polygon: 52S 70W -
52S 31.5W - 57S 31.5W - 65S 61W - 52S 70W.

EQ#	YR	MO	DY	TIME	LAT.	LON.	DHP	MAG	#STA.	#P	#F.M.	ERROR(DEG)	FOC.MEC.?
N 1	33	12	2	200512.	52.4	58.8*	10	6.5	57	9	0	.39,2.5	
N 2	34	7	4	14234.	55.8	49.6*	10	6.2	44	7	2	.32,2.3	
N 3	41	12	1	195620.	54.3	57.6*	10	6.2	29	14	1	.20,1.1	
N 4	49	12	19	74036.	54.7	63.8*	10	0.0	16	7	0	1.7,1.9	
N 5	52	8	19	210524.	53.5	53.5*	33	0.0	65	15	1	.19,.32	
N 6	64	9	15	202335.	54.4	53.3	33	5.0	30	24	3	.07,.16	
N 7	65	9	26	213355.	54.7	38.3	33	5.9	145	68	19	.05,.10	For
N 8	66	10	27	14520.	54.4	39.0	33	4.7	10	9	3	.08,.13	
N 9	70	6	15	111454.	54.3	64.2	38	5.7	285	122	16	.05,.13	For
N 10	70	7	10	70004.	55.8	48.4	33	4.9	27	22	4	.06,.14	
N 11	71	3	2	004543.	54.2	53.9	33	4.9	50	35	4	.11,.20	
N 12	72	5	15	220730.	55.2	33.1	33	4.5	19	12	3	.06,.12	
N 13	72	7	14	25330.	55.8	48.0	42	4.8	44	29	5	.05,.10	
N 14	73	12	03	184208.	54.7	32.0	0	4.8	7	7	0	.26,.68	
N 15	78	11	27	182428.	54.1	59.1	30	5.0	64	43	11	.03,.07	yes

deformation 300 kilometers wide stretching from 30W to 70W. Constrainable focal mechanisms in the region show a northeasterly directed thrust, a southwesterly directed thrust and a left-lateral strike-slip event. There are two earthquakes along this zone of seismicity in the period 1964 - 1980 with more than 130 stations reporting, with maximum Mb of 5.9. Historic seismicity gives three earthquakes of M = 6.0 or over. This zone of seismicity does not follow the North Scotia Ridge, but from west to east cuts Tierra del Fuego, Burdwood Bank, the floor of the Scotia Sea and the south shelf of South Georgia Island (see table 8 and figure 13).

The major evidence for calling this zone of seismicity a strike-slip plate boundary is the June 15, 1970 earthquake. The focal mechanism is strike-slip (Forsyth, 1975), and it aligns well with the general trend of the seismicity. The other two mechanisms that have been determined (Sep. 9, 1965 (Forsyth, 1975), Nov. 27, 1976) show thrust fault mechanisms, however.

The June 15, 1970 event occurs the day after the large (296 stations, Mb = 6.0, Ms = 6.7) June 14, 1970 strike-slip earthquake that occurred off the south Chile coast. This event, its three aftershocks and the north boundary event all lie within 500 kilometers of each other, and occur within 30 hours of each other (tables 7,8). The connection suggested here is a doublet mechanism, where one large earthquake is triggered by another (Lay and Kanamori, 1981).

Lay and Kanamori(1981) describe the fact that large, thrust earthquakes in the Solomon Islands tend to be double, the earthquakes occurring within 12 days of each other, and 200 kilometers of each other. As with their explanation of these occurrences, the significance of this pair of large earthquakes in the Scotia Sea area is that there must be a continuity in the plate boundary from one to the other.

This mode of occurrence was checked in older records, and one similar occurrence was found, again for the south Chile coast and the north boundary of the Scotia plate. In 1949 a series of 5 earthquakes occurred within 45 days of each other, 3 of magnitude 7.0 or greater. The north Scotia Sea earthquake for this seqence occurred 40 hours after the initial shock (event N4, table 8). This suggests a continuing connection between the north Scotia Sea boundary and the south Chile coast boundary.

Also, large earthquakes on the south Chile coast occur periodically every 10 years (1949, 1959, 1970, 1979) with only few small earthquakes seen in between. This leads to the observation that the Chilean earthquakes, being strike slip in mechanism, are building up stress over a regular interval, then releasing it at one time, showing that the motion is taken up seismically rather than aseismically in creep in this region.

Lastly, it is seen that the stresses transmitted to the north Scotia Sea zone of seismicity extend to the point where the zone leaves the South American continent. To the east of this point, the zone of seismicity broadens and weakens, and the focal mechanisms seen are dip-slip rather than strike-slip. From this, it is possible that east of the South American continent only a broad zone of deformation is defined rather than a plate boundary. Unfortuantely, composite focal mechanisms constructed over the whole zone are poor in quality because of the paucity of earthquakes. The composite mechanism constructed is equally likely to be strike-slip or dip-slip. Breaking the north Scotia Sea zone of seismicity into two or more parts yields even more meaningless results because of the lack of events. Also, since no similar earthquakes to the doublets are seen on the Shackleton (no Shackleton earthquakes occur within 30 days of the south Chilean coast earthquakes), it reemphasizes the fact that the Shackleton plate boundary has no direct connection with the south Chilean coast plate boundary, except by the supposed aseismic zone of creep between 56.5S and 54S.

Scotia Sea Back Arc Spreading Center

The Scotia Sea back arc spreading center is characterized by low magnitude seismicity in a rough north - south line along 30S. Only one earthquake in the period 1964 - 1980 had over 30 stations reporting, and no historical seismicity has been reported. A composite mechanism of 9 earthquakes in this area was inconclusive, showing predominantly normal faulting mechanisms but giving no constraints on the angles of strike and dip (figure 14; table 9).

This lack of seismicity is expected, as low seismicity is associated with other fast spreading Ridges, such as the East Pacific Rise (Forsyth, 1975).

Table 9 -
South Sandwich back arc spreading
center earthquakes:
Confined to the polygon 31W 56S -
28W 56S - 28W 59.5S - 31W 59.5S - 31W 56S
(* means relocated)

#	YR	MO	DY	TIME	LAT.	LON.	DHP	MAG	#STA.	#P	#FM	ERROR
1	52	9	28	141616.	57.4	28.2*	10	0.0	29	7	2	.14,.14
2	54	3	12	111209.	58.2	27.8*	10	0.0	41	11	3	.21,.22
3	65	4	8	203059.	57.8	29.0	97	0.0	17	9	3	.06,.15
4	66	3	1	89853.	56.2	29.3	33	0.0	11	6	1	.10,.19
5	67	5	22	200960.	59.5	29.9	33	4.7	22	14	2	.04,.08
6	68	7	21	235421.	58.4	29.6	33	4.6	29	19	4	.04,.08
7	68	7	22	72951.	58.7	29.1	33	4.6	21	10	0	.08,.16
8	74	8	6	195401.	56.1	30.2	40	5.7	37	21	2	.20,.34
9	75	6	21	1529.	59.5	29.6	33	0.0	12	8	1	.03,.09
10	78	6	11	61155.	57.2	30.0	16	4.9	17	15	3	.05,.08

Northwest South Sandwich Subduction Zone

The area in question lies along the northern most extension of the South Sandwich subduction zone from 28W to 30W, where it should intersect with the Scotia Sea back arc spreading center. The focal mechanisms of the area should show a change from thrusting in the east to strike-slip in the west. Vertical dip-slip mechanisms should result from hinge faulting caused by a tearing of the subducting slab away from the non - subducting slab (Forsyth, 1975).

In the time period 1950 - 1980 there were four earthquakes with over 80 stations reporting, the largest given a Mb = 5.5 and had 143 stations reporting (table 10). Only three fully constrained focal mechanisms exist for this area, one showing left-lateral strike-slip, with a strike 60 degrees east of north, the other two showing vertical dip-slip (figure 14). Shallow seismicity in this area of the arc is strike-slip, and strikes roughly east-west. A composite mechanism constructed from 22 small earthquakes in the area during the period 1950 - 1980 shows a similar left-lateral strike-slip mechanism, with its strike 60 degrees east of north.

Also in this area is expected the triple junction between the subduction zone, spreading center and north boundary of the Scotia Sea. As the principal compressive

Table 10 -
North West Arc earthquakes:
Bounded by this polygon - 55S 30.5W TO
55S 27.5W TO 56S 30.5W TO 55S 30.5W
(* means relocated)

	#	YR	MO	DY	TIME	LAT	LON	DHP	MAG	#AR	#P	#FM	ERROR(DEG)	FOC.MEC.?
E	1	30	3	30	082610.	55.4	29.2*	10	6.8	48	11	0	.45,.93	
E	2	67	7	12	215234.	55.7	29.8	29	5.0	16	11	5	.11,.17	
E	3	67	8	15	165700.	55.4	29.6	33	4.6	21	10	3	.11,.21	
E	4	67	11	25	215158.	55.3	29.1	33	5.2	38	21	7	.07,.08	
E	5	67	11	26	34937.	55.2	29.0	33	5.1	22	14	5	.09,.11	
E	6	68	1	20	172429.	55.5	29.7	33	0.0	25	11	4	.16,.37	
E	7	69	6	22	104752.	55.3	29.3	38	5.0	30	17	3	.05,.06	
E	8	69	6	11	33623.	55.2	30.2	34	4.9	42	22	6	.06,.09	
E	9	68	12	16	90605.	55.0	29.3	33	4.5	23	9	1	.47,.60	
E	10	70	5	9	84356.	55.6	29.3	33	4.9	22	18	1	.04,.08	
E	11	71	5	13	35430.	55.7	30.1	33	5.5	9	7	1	.08,.12	
E	12	72	3	31	153634.	55.3	29.1	33	5.5	143	69	20	.04,.08	For
E	13	72	4	10	84742.	55.7	29.8	33	4.7	22	18	1	.08,.13	
E	14	72	5	5	193834.	55.3	29.2	33	5.1	84	37	9	.07,.11	yes
E	15	73	9	25	32319.	55.2	28.7	33	5.0	35	21	7	.06,.08	
E	16	73	11	7	42312.	55.4	29.4	33	4.9	33	24	8	.06,.06	
E	17	75	3	22	62809.	55.1	28.0	33	5.0	20	13	4	.09,.12	
E	18	77	6	6	11425.	55.2	29.1	33	5.2	64	49	8	.07,.08	yes
E	19	77	6	6	12960.	55.3	29.0	33	5.3	97	49	13	.06,.08	yes
E	20	77	6	6	23921.	55.1	28.6	33	5.1	33	17	2	.08,.11	
E	21	77	6	6	25545.	55.0	28.7	33	4.7	20	12	2	.14,.19	
E	22	77	10	9	92245.	55.5	29.2	33	5.1	15	12	1	.16,.24	
E	23	78	1	3	43525.	55.3	29.6	33	4.7	16	6	0	.11,.14	
E	24	79	6	1	153724.	55.6	30.0	33	5.2	38	29	4	.06,.09	

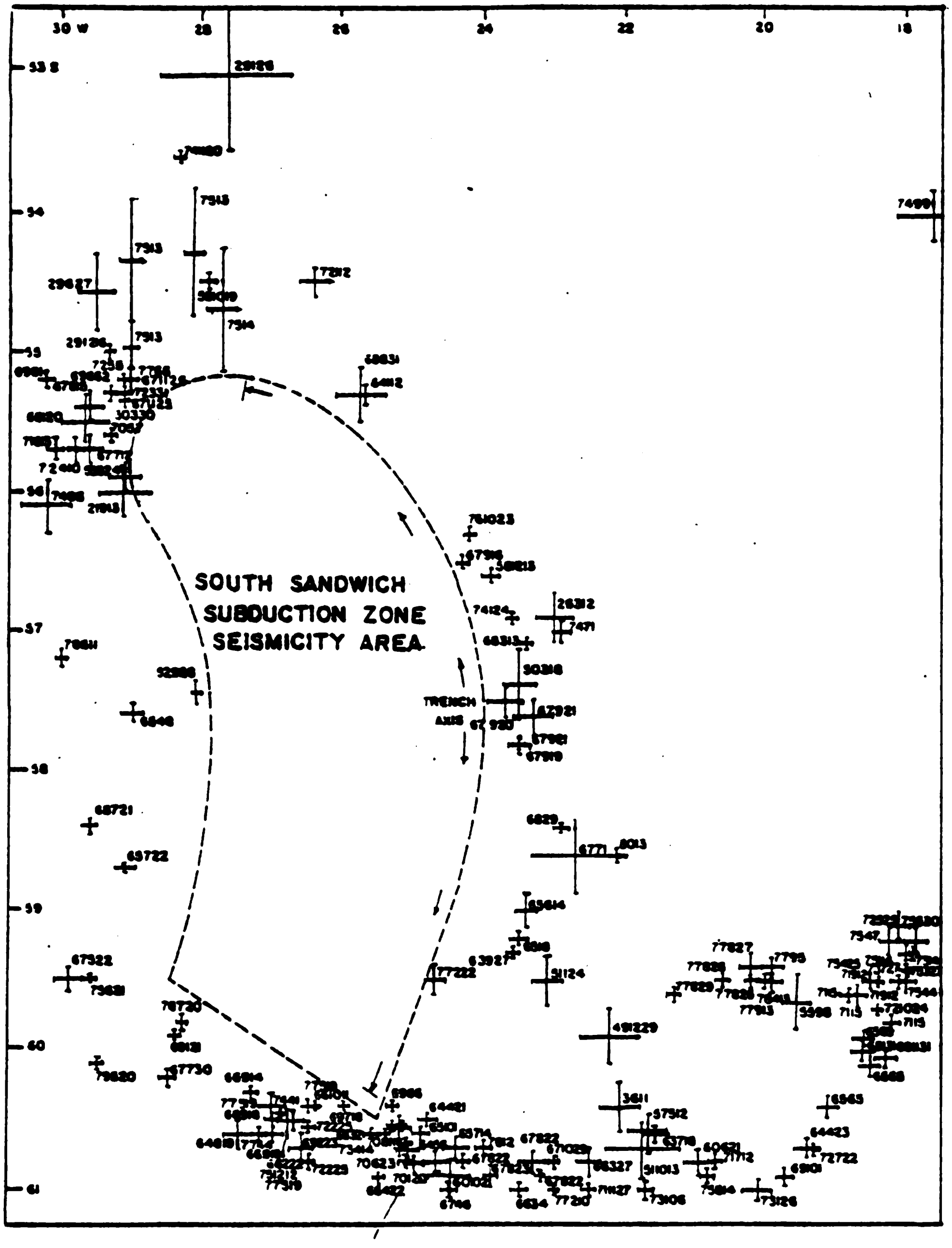


Figure 14 - Seismicity of the South Sandwich Arc Region

stresses determined from the focal mechanisms lie north-south, it can be seen that this area of the arc is being compressed north - south and being extended east to west.

Alternatively, these earthquakes could represent transform motion on a slower section of the back arc spreading center, which would also indicate east west extension in the area (Forsyth, 1975). The significance of the large dip-slip event is in hinge faulting, as explained above. This process is also seen at the north edge of the Tonga Trench (Isacks, et al., 1969).

South Sandwich Outer Rise

The outer rise of the South Sandwich trench is a bathymetric high that stretches from 60S 24W to 54S 30W. The area of the outer rise shows relatively high seismicity for the region - four earthquakes with over 100 stations reporting in the period 1958 - 1980, three having Mb of 6.0 or larger (table 11). This is roughly comparable to what is seen worldwide, with worldwide outer rise seismicity of 30 Ms >= 6.0 earthquakes in the decade of the 1960s (Hanks, 1979).

All outer rise earthquakes in this region lie within 150 kilometers of the trench and all but two (including three of the four with more than 100 stations reporting) lie within 50 kilometers of the trench. This is expected, as Hanks (1979) notes that the strongly deformed region 50 - 150 kilometers seaward of the trench is notably aseismic at the Ms >= 6.0 level. Recent analyses suggest that outer rise earthquake locations in this distance range and for this length of slab should be virtually unaffected by the subducting slab's effects on travel times of raypaths, in contrast to thrust zone earthquakes, which are often mislocated deeper and trenchward by simple location algorithms (Rogers, 1982; Engdahl et al., 1982).

The 7 focal mechanisms constructed for the area show

Table 11 -
South Sandwich Arc outer rise earthquakes:
Area bounded by the arc on the southwest
and by 59S on the south.
(* means relocated)

	#	YR	MO	DY	TIME	LAT.	LON.	DHP	MAG	#STA.	#P	#FM	ERROR(DEG)	FOC.MEC.?
0	1	28	3	21	141912.	58.9	23.0*	20	7.1	79	12	0	.18,.24	
0	2	28	5	15	54345.	51.1	27.7*	10	6.0	37	9	0	.85,.72	
0	3	29	6	27	124714.	54.8	29.6*	10	0.0	143	31	0	.20,.34	
0	4	29	12	6	164643.	53.0	27.6*	10	6.7	83	18	0	.68,.65	
0	5	50	3	18	43934.	57.4	23.5*	10	0.0	44	13	0	.24,.22	
0	6	58	12	13	90734.	56.6	23.9*	10	0.0	57	25	7	.05,.13	
0	7	59	10	19	155530.	54.5	27.7*	10	6.0	167	58	17	.09,.18	yes
0	8	61	9	27	120728.	59.3	23.6*	10	6.0	154	45	19	.05,.11	yes
0	9	64	11	29	165426.	55.3	25.7	33	5.2	30	20	2	.07,.14	
0	10	65	1	8	184945.	59.2	23.5	39	5.6	71	30	18	.05,.10	yes
0	11	65	6	14	100240.	59.0	23.4	33	0.0	22	9	1	.10,.18	
0	12	67	7	1	94603.	58.6	22.5	250	5.1	25	11	1	.25,.63	
0	13	67	9	16	231239.	56.5	24.3	31	4.4	13	8	1	.04,.04	
0	14	67	9	19	124536.	57.8	23.5	34	6.0	145	59	26	.04,.08	yes
0	15	67	9	20	214041.	57.5	23.7	31	4.6	12	9	2	.12,.25	
0	16	67	9	21	173925.	57.6	23.3	0	4.5	14	6	0	.13,.27	
0	17	67	9	21	204033.	57.8	23.5	33	4.9	21	12	1	.06,.12	
0	18	68	2	9	113260.	58.4	22.9	33	0.0	18	7	1	.03,.10	
0	19	68	3	13	93148.	57.1	23.4	33	5.0	52	25	6	.04,.08	
0	20	69	8	31	95301.	55.3	25.7	43	4.8	30	16	1	.21,.36	
0	21	70	7	1	55808.	57.0	22.9	31	4.9	35	17	3	.07,.12	
0	22	72	11	2	194840.	54.5	29.2	33	4.9	17	14	6	.12,.21	yes
0	23	74	9	9	192752.	54.0	17.6	33	4.8	7	7	1	.18,.49	
0	24	74	11	20	134242.	53.6	28.3	36	5.8	114	65	24	.04,.06	yes
0	25	74	12	4	194330.	58.9	23.6	40	5.1	51	35	12	.04,.08	yes
0	26	75	1	3	65154.	54.3	29.0	33	0.0	9	7	2	.48,.15	
0	27	75	1	4	911.	54.7	27.7	33	4.7	11	10	3	.43,.19	
0	28	75	2	21	3813.	52.5	17.4	33	4.8	46	31	3	.15,.17	
0	29	76	10	23	225023.	56.3	24.2	33	5.1	54	20	4	.05,.08	
0	30	77	2	22	260953.	59.5	24.7	35	4.9	31	19	5	.10,.12	
0	31	78	3	7	201831.	58.3	24.9	33	5.6	22	14	3	.11,.13	
0	32	78	10	11	175424.	56.6	24.4	33	4.7	15	9	1	.25,.52	
0	33	79	2	16	84253.	58.6	23.4	33	5.1	41	26	6	.06,.09	
0	34	80	1	3	105116.	58.6	22.1	10	5.4	31	20	4	.05,.11	

that normal faulting dipping toward the arc predominates in the region within 50 kilometers of the trench. Within 50 kilometers of the trench are three normal faults striking parallel to the trench and one poorly constrained normal fault, striking perpendicular to the trench. This event, Sep. 19, 1967, has an Mb = 6.0 and is located at 58S 23.5W (see Analysis - rate calculations), and is possibly related to near vertical faulting along a fracture zone caused by bouyancy differences between two slabs of different ages (Frankel and McCann, 1979; Brett, 1977). Another earthquake, at 59.3S 23.6W, shows a strike-slip mechanism. This event could be related to a seaward strike-slip fault(see South America - Antarctic spreading ridges) (figure 14).

Two composite mechanisms were made, one for the segment north and the other for the segment south of 58S. The two groups were separated because of seismic and tectonic differences occurring north and south of 58S (Forsyth, 1975; Brett, 1977). Both composites only constrain one plane, but have normal faulting mechanisms. The north mechanism strikes 120 degrees east of north, and the south mechanism strikes north - south, each mirroring the strike of the nearby trench. This is consistent with the strikes of outer rise earthquakes seen seaward of the Aleutians, central Chile and seaward of the Kurile - Kamchatka arc (Stauder, 1968; Stauder, et al.,1975). The general alignment of the strikes with the trench axis and the nearness of the hypocenters to the trench axis is expected from the theories of plate bending (Hanks, 1979).

Of the three events in the 50-150 kilometer range, two give focal mechanisms with a near vertical plane constrained, suggesting thrust faulting; the other earthquake is unconstrained. One, the Nov. 2, 1972 earthquake, is close enough to the outer rise crest to be considered possibly dipping downslope to the trench, and thus also could be an arcward dipping reverse fault. The other, Nov. 20, 1974, is located 150 kilometers north of the trench, and can either be interpreted as a thrust (breaking on the horizontal plane) or a vertical dip-slip event (breaking on the vertical plane). It is a large earthquake for the area it occurs in, with Mb = 5.8, and is also far enough away from the trench to be considered an intraplate event, and thus merits further study. The strike of the earthquake is parallel to the strike of the South Sandwich trench, and is also parallel to the strike of a fracture zone that the earthquake locates on, suggesting a more complicated reason for the event than just an isolated intraplate event.

Explanations for the second earthquake are that the event represents typical intraplate thrusting or that the event represents vertical faulting related to the bending of the South American oceanic plate in the region. Intraplate compression (thrusting) is the observed mechanism in most intraplate events (Wang, et al., 1979), with the faulting occurring on preexisting faults (such as the fracture zone). This would also be consistant with the observation of Wang (1979) that indicates that the mechanisms of intraplate earthquakes do not mirror the regional strain in the area, as intraplate events tend to break on old faults.

The other possibility is that the break was on the vertical plane, with the explanation for this vertical motion being that the South Atlantic plate is bending downward in this area. Forsyth (1975) has suggested that the north end of the South Sandwich arc - trench system shows hinge faulting (Forsyth 1975), the reason for a bathymetric depression of 5 kilometers that extends several hundred kilometers north of the trench. Since the mechanism shows compression of the south, the earthquake could be mirroring lithospheric bending of the south ocean floor relative to the higher floor to the north. An explanation for why the faulting is vertical could be that the local stress is being relieved on a previously existing fault (the fracture zone) on which the earthquake occurs.

Unfortunately, because of limitations of the method, further analysis via Rayleigh wave modeling cannot constrain the sense of motion of the fault blocks for either of the two events, and thus was not done.

Southwest South Sandwich Subduction Zone

A boundary between the Antarctic plate and the Sandwich plate can be predicted on the basis of geometry. Previously, the expected right-lateral strike-slip boundary had not been observed by the seismicity (Forsyth, 1975). This boundary has active seismicity, with two events in the period 1960 to 1980 having Mb = 5.9, and five earthquakes in the same period having over 100 stations reporting arrivals (table 12). No historical seismicity is reported before 1960, as might be expected as a result of the inability to detect earthquakes in the area with M less than 6.0 prior to 1958.

Examination of historic and recent seismicity shows that the southern edge of the seismicity abruptly ends along a line trending about 110 degrees east of north (figure 14). Examination of focal mechanism geometries show three possible types of events along this zone - shallow right-lateral strike-slip earthquakes connected with movement between the overriding plate and the Antarctic plate, deep compressional earthquakes in the subducting slab (Forsyth, 1975), and shallow thrust earthquakes from contact between the overriding slab and the subducting slab (figure 14). Because of mislocation effects due to velocity inhomogeneities in the subducting slab, these last category

Table 11 -
South arc boundary earthquakes:
Area bounded by this polygon: 60.5S 25.5W to 61S 25.5W to 60.5S 30W to 59S 30W to 60.5S 25.5W. (* means relocated)

	#	YR	MO	DY	TIME	LAT.	LON.	DHP	MAG	#STA.	#P	#FM	ERROR(DEG)	FOC.MEC.?
W	1	60	11	9	31755.	60.9	25.5*	10	0.0	183	52	14	.05,.09	
W	2	64	8	19	13054.	60.6	27.5	33	0.0	21	17	2	.11,.20	
W	3	66	2	22	1709.	60.5	26.8	33	5.0	25	13	6	.08,.13	
W	4	66	9	14	231842.	60.3	27.3	27	5.9	244	71	25	.04,.10	For
W	5	66	9	18	151424.	60.5	26.7	27	5.2	59	38	13	.07,.15	yes
W	6	66	9	18	184659.	60.5	27.0	41	5.2	45	26	10	.05,.10	
W	7	66	9	19	184660.	60.6	27.0	33	4.7	24	14	4	.06,.15	
W	8	66	10	11	62558.	60.4	26.4	35	5.8	182	71	30	.03,.07	For
W	9	67	5	22	200960.	59.5	29.9	33	4.7	22	14	2	.08,.23	
W	10	67	7	30	81928.	60.2	28.5	33	5.2	56	35	7	.06,.11	yes
W	11	68	3	2	111355.	60.6	25.6	0	5.1	58	26	4	.04,.09	
W	12	68	2	23	143528.	60.7	26.6	33	4.8	28	12	2	.10,.16	
W	13	69	7	18	141355.	60.4	26.0	41	5.4	83	42	19	.03,.07	
W	14	69	12	1	203505.	60.0	28.5	150	5.6	112	53	17	.03,.06	For
W	15	72	2	25	11715.	60.6	26.5	40	5.9	200	85	18	.08,.11	For
W	16	72	2	25	25249.	60.8	26.5	33	5.1	65	36	4	.06,.11	
W	17	73	4	14	200036.	60.6	25.6	33	4.8	23	15	5	.04,.06	
W	18	74	4	1	202418.	60.4	26.9	94	5.3	93	40	13	.04,.07	yes
W	19	75	6	21	1529.	59.5	29.8	33	0.0	12	8	1	.03,.09	
W	20	75	12	19	134011.	60.5	26.8	33	4.9	39	18	4	.11,.17	
W	21	76	7	20	92438.	59.8	28.3	33	5.1	33	27	11	.05,.09	yes
W	22	77	4	4	22936.	60.6	27.2	63	5.2	60	29	3	.05,.09	
W	23	77	5	19	170253.	60.4	28.5	33	5.2	61	40	6	.06,.09	
W	24	77	5	19	173517.	60.4	27.0	33	5.1	57	34	5	.10,.12	
W	25	79	5	20	030234.	60.2	29.5	45	5.5	98	68	14	.06,.09	yes

hypocenters are suspect (Fujita et al., 1981). It is then expected that some shallow thrust zone earthquakes would mislocate west into this area.

Along this boundary nine moderately to well constrained focal mechanisms can be determined. Five show right-lateral strike-slip faulting, striking along the strike of the edge of the seismicity. These are all shallow earthquakes, the deepest being listed in the bulletins as at 45 kilometers. There is one left-lateral strike-slip event. It is given a depth of 45 kilometers, and if it is mislocated west of its real hypocenter it could represent motion between the subducting plate and the Antarctic plate. Of the three thrust mechanisms, two are located deep (90 kilometers and 130 kilometers), and the other shallow (27 kilometers). The deep earthquakes obviously represent activities in the underthrust plate. The shallow earthquake, a thrust with strike parallel to the trench axis, could either be a mislocated thrust zone earthquake or represent thrusting of the Antarctic plate westward over the rapid South Sandwich plate.

South America - Antarctic Spreading Ridges

This area lies along a region of high bathymetry generally east of the South Sandwich trench. The main connection between the South America - Antarctic spreading center and the arc is the South Sandwich fracture zone, a transform fault along 60.5S, showing high seismicity. A northeast trending spreading Ridge then extends from the east end of this fracture zone at 19.5S north northeast to 59S 17.5W, showing moderately active (transform fault) seismicity. A third, less well defined zone of activity extends westward along a poorly defined (bathymetricly) fracture zone at 59.5S (Gebco General Bathymetric chart of Oceans, 1981).

Seismicity along the South Sandwich fracture zone shows 7 earthquakes with 100 or more stations reporting in the period 1960 to 1979, four having Mb = 6.0 or greater, the largest having Mb = 6.3. Historically, there are two M = 7.0 or greater earthquakes on this feature, and it is unlikely that they could be mislocated trench events (table 13). Ten focal mechanisms were able to be constructed from those earthquakes located on this feature, with 9 showing left-lateral strike-slip, the 10th, Aug. 11, 1970, showing one constrained plane, is a normal fault with strike roughly parallel to the nearby trench. Although not resolvable with

Table 13 -
South America - Antarctic ridge earthquakes:
Zone from the South Sandwich arc east
to 17 E. F means that the earthquake is
located along the 59.5S fracture.(* means relocated)

	#	YR	MO	DY	TIME	LAT.	LON.	DHP	MAG	#STA.	#P	#FM	ERROR(DEG)	FOC.MEC.?
M	1	38	1	14	53630.	60.4	22.1*	50	7.2	100	20	1	.18,.29	
M	2F	49	12	27	235716.	59.9	22.2*	50	7.1	140	33	4	.19,.38	
M	3	50	11	20	122624.	61.7	19.5*	10	0.0	14	5	1	.27,.33	
M	4F	51	1	24	44925.	59.5	23.1*	10	0.0	69	14	4	.19,.18	
M	5	51	10	13	222806.	60.7	21.7*	10	0.0	80	18	3	.21,.56	
M	6F	55	9	8	20319.	59.7	19.6*	10	6.5	120	26	7	.20,.22	
M	7	57	5	12	44744.	60.6	21.7*	10	0.0	109	28	6	.14,.36	
M	8	60	4	5	71744.	60.7	25.0*	10	0.0	66	25	7	.10,.20	
M	9	60	4	5	123614.	60.7	25.2*	10	0.0	60	28	10	.09,.18	
M	10	60	6	21	213345.	60.8	20.9*	10	5.9	94	30	6	.12,.24	
M	11	60	10	2	043741.	60.9	24.5*	10	0.0	40	22	5	.15,.33	
M	12	61	9	19	213438.	60.4	24.4*	10	6.5	94	30	8	.04,.09	
M	13	63	7	18	45809.	60.7	21.6*	10	6.0	131	36	11	.06,.17	
M	14	64	4	23	70320.	60.7	19.4	33	5.4	15	9	2	.06,.14	
M	15	64	4	26	223449.	60.5	24.8	33	5.2	33	15	4	.05,.13	
M	16	64	5	6	42707.	60.8	24.7	64	5.4	52	24	6	.08,.16	
M	17	64	8	19	13054.	60.6	27.5	33	0.0	21	17	2	.11,.20	
M	18	65	6	5	123917.	60.1	18.5	33	0.0	33	19	4	.07,.15	
M	19	65	6	5	124319.	60.4	19.1	33	0.0	15	8	2	.08,.14	
M	20	65	8	5	130023.	59.9	18.6	33	0.0	42	18	7	.06,.13	
M	21	65	7	14	101203.	60.7	24.4	33	5.7	30	16	6	.09,.18	
M	22	65	10	1	223425.	60.6	24.9	33	5.7	89	40	14	.06,.12	
M	23	66	2	27	3153.	60.8	22.5	33	5.1	30	17	8	.10,.13	
M	24	66	3	4	53416.	61.0	23.5	114	5.0	26	15	5	.06,.13	
M	25	66	4	22	121737.	60.6	25.4	33	5.1	63	29	13	.04,.08	
M	26	67	4	6	182625.	61.0	24.5	35	5.1	15	9	3	.04,.11	
M	27	67	8	22	130207.	60.8	24.3	33	6.1	272	91	35	.04,.10	For
M	28	67	8	22	131703.	60.9	23.2	19	5.6	97	38	15	.03,.08	yes
M	29	67	8	22	171441.	60.8	23.3	31	4.8	18	10	3	.08,.11	
M	30	67	8	23	141639.	60.9	23.9	33	5.0	19	12	3	.04,.08	
M	31	67	10	29	123719.	60.8	23.0	10	5.2	59	32	2	.04,.08	
M	32	68	1	31	90029.	60.0	18.6	32	5.0	25	13	1	.09,.16	
M	33	68	10	2	71912.	60.7	25.2	33	5.0	32	20	7	.03,.07	
M	34	68	11	23	164148.	60.1	18.3	33	4.8	21	10	3	.08,.18	
M	35	69	6	6	121225.	60.4	25.3	33	5.0	34	15	6	.04,.08	
M	36	69	10	1	195316.	60.9	19.7	33	5.6	105	59	8	.06,.11	For
M	37	70	1	20	20953.	60.8	25.0	33	4.7	23	10	3	.07,.12	
M	38	70	6	23	33836.	60.8	25.1	40	5.3	75	36	2	.05,.12	
M	39	70	8	11	201054.	60.6	25.3	45	5.8	176	74	27	.04,.08	yes
M	40	71	1	5	50431.	59.8	18.2	33	4.6	14	10	1	.06,.11	
M	41	71	1	5	53921.	59.6	18.7	33	0.0	20	11	4	.07,.15	
M	42	71	7	12	184922.	60.8	20.7	33	4.8	23	20	2	.05,.11	
M	43	71	9	12	41617.	59.5	18.5	61	5.1	49	32	3	.04,.08	
M	44	71	9	12	51342.	59.5	18.4	33	4.8	20	13	1	.03,.08	
M	45	71	11	5	200431.	59.6	18.8	33	0.0	12	10	2	.05,.12	
M	46	71	11	27	32714.	61.0	22.5	53	5.3	42	25	8	.05,.10	
M	47	72	5	25	132238.	59.1	18.1	33	4.8	24	18	2	.11,.16	
M	48	72	7	22	31656.	60.7	19.3	33	5.1	109	56	10	.04,.07	yes
M	49	72	10	24	14346.	59.7	18.4	33	4.9	20	12	2	.04,.08	
M	50	73	1	4	91032.	58.3	17.9	33	5.4	63	37	15	.04,.06	yes

Table 13 (Cont.)

South America - Antarctic ridge earthquakes (cont):

	#	YR	MO	DY	TIME	LAT.	LON.	DHP	MAG	#STA.	#P	#FM	ERROR(DEG)	FOC.MEC.?
M	52	73	10	6	150738.	61.0	21.7	33	6.2	327	119	31	.06,.11	yes
M	53	73	10	7	133551.	61.2	22.4	33	5.0	17	12	1	.10,.23	
M	54	73	12	6	111150.	61.0	20.1	33	4.7	15	11	0	.08,.19	
M	55	75	2	21	195123.	60.6	25.2	33	5.0	25	14	4	.11,.19	
M	56	75	3	27	153916.	59.5	18.1	33	5.3	106	35	12	.05,.10	yes
M	57	75	4	4	205434.	58.5	18.0	33	5.0	28	17	1	.07,.15	
M	58	75	4	7	80555.	59.2	18.2	33	0.0	28	14	5	.12,.17	
M	59	75	4	25	15127.	59.5	18.0	33	4.8	16	12	2	.04,.07	
M	60	75	5	30	200914.	59.2	17.9	33	5.1	47	29	7	.12,.18	
M	61	75	8	14	50417.	60.9	20.8	33	5.1	25	18	5	.08,.10	
M	62	75	11	4	102326.	59.4	18.0	33	5.1	35	23	7	.05,.10	
M	63	76	1	2	73542.	60.7	24.0	94	4.9	20	14	1	.06,.09	
M	64	77	2	10	224107.	61.0	23.0	33	6.1	233	98	33	.05,.10	yes
M	65F	77	8	26	195002.	59.5	20.6	33	6.3	334	134	41	.05,.09	yes
M	66F	77	8	26	223860.	59.5	20.2	33	4.8	35	25	4	.04,.07	
M	67F	77	8	27	1602.	59.4	20.2	33	4.4	15	11	2	.11,.16	
M	68F	77	8	29	123240.	59.6	21.3	33	5.2	86	55	12	.06,.08	
M	69F	77	9	5	92311.	59.4	19.9	33	5.1	23	16	5	.07,.14	
M	70F	78	4	13	152438.	59.5	19.9	33	4.8	15	11	2	.08,.17	
M	71	78	11	27	193411.	59.7	17.1	33	4.7	22	17	1	.21,.36	
M	72F	78	9	13	200056.	59.3	20.0	10	0.0	0	14	1	.05,.11	

the given location techniques, it is reasonable to assume that this event is not located on the transform, but on the outer rise, which intersects the fracture zone at this point (see figure 14).

The ridge of the spreading center is marked by a series of moderate to small earthquakes, only two in the period 1960 - 1980 having more than 100 stations reporting, with Mb of 5.1 and 5.3 respectively. All three focal mechanisms constructed show strike-slip motion, two showing the expected left-lateral motion, one showing right-lateral strike-slip motion. A composite mechanism for this feature (made from 15 small earthquakes) also shows left-lateral strike-slip motion. The right-lateral strike-slip mechanism will be considered below.

The third group forms a linear feature along the 59.5S, and is made up of 7 recent earthquakes and one historical earthquake. The 7 recent earthquakes occurred between August 1978 and December 1979, the largest of which, (Aug. 26, 1978), has 334 stations reporting, Mb = 6.3, Ms = 7.1 (Creaven, et al., 1979). Investigation of the WWSSN records show that this was a double event. In figure 15, short and long period arrivals from station NNA of the Aug. 26, 1978 event are plotted, showing two distinct arrivals 3.6 seconds apart. It was possible to construct focal mechanisms for both events, and both show right-lateral strike-slip motion with a strike along 90 degrees east of north. No other earthquakes in the recent sequence were large enough to construct focal mechanisms from, but a composite mechanism constructed of all but the main events also gives a right-lateral strike-slip solution.

Three other earthquakes are on line with this group (to the west), and one (Sept. 27, 1961) also gives a focal mechanism of right-lateral strike-slip. The strike of this event is 75 degrees east of north. Also, as mentioned earlier, to the east of the Aug. 26, 1978 earthquake, near the spreading ridge, but on line with the 59.5 fracture, is another right-lateral strike-slip earthquake.

These four mechanisms and composites lead to the conclusion that there is a previously unknown zone of deformation or plate boundary lying at 59.5S. Bathymetry of the area shows an east-west trending fracture zone. Tectonic significance of this zone is that the ocean floor to the south of the fracture zone is being subducted at a more rapid rate than the ocean floor to the north. This would seemingly be in reverse of what is expected, as the south is younger than the north and the north should tend to be subducted faster than the south (Brett, 1977).

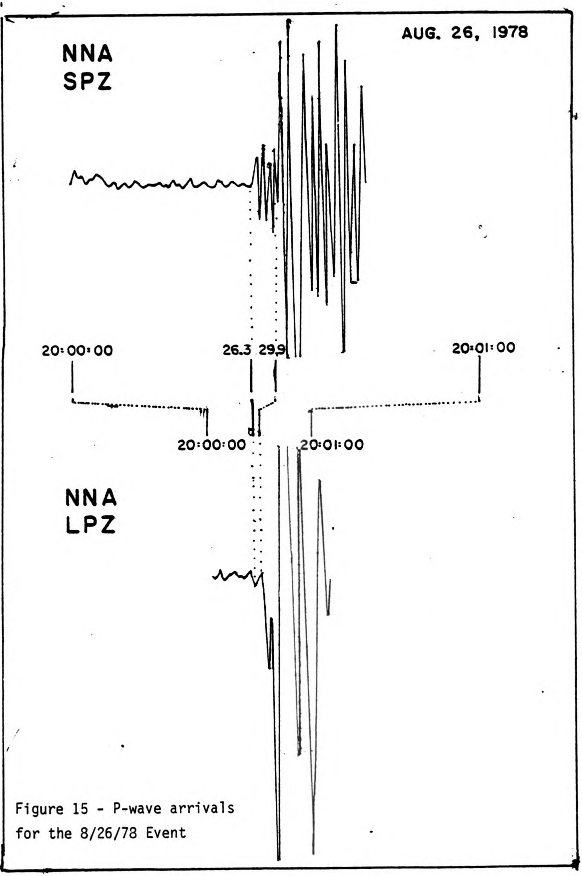


Figure 15 - P-wave arrivals for the 8/26/78 Event

ANALYSIS AND CONCLUSIONS

Rate Calculations

Literature values for the rate of convergence of the South Sandwich subduction zone range from a low of 2.0 centimenters per year (Fujita and Kanamori, 1981) to 7 - 9 centimeters per year (Barker, 1972; Frankel and McCann, 1979). The spreading rate on the South Sandwich back arc spreading center is calculated by magnetic lineations to be 7 - 9 centimeters per year, full rate (Barker, 1972). The Antarctic - South American slip rate is given at between 1.6 centimeters per year (Minster and Jordan, 1978) and 2.0 centimeters per year (Forsyth, 1975), calculated from spreading rates given on all sides of the Scotia Sea.

Using the methodology of Davies and Brune (1971) the seismic moments calculated from surface wave magnitude Ms can in theory be related to slip rates along fault planes. Calculations from recent data over a short period of time give a very slow convergence rate (.5 cm./year), while rates calculated using pre 1957 data (Gutenberg and Richter, 1954) give a convergence rate of 4.5 cm./year. The actual rates calculated for the time period (1963 - 1979) are expected only to give comparison to other regional data, and are not meant as actual rate calculations for two reasons: The first that the period of time used in collecting the data was small, thus losing the effect of infrequent large earthquakes from the calculations. The second is that the subduction zone is suspected of having a large degree of aseismic slip (Brett, 1975), similar to that seen in the Caribbean (Molnar and Sykes, 1969; Westbrook, 1975).

The relationship between the magnitude calculated from surface waves (Ms) and seismic moment Mo is given empirically as:

$$(1) \quad \mathrm{LOG}_{10}\ \mathrm{Mo} = \mathrm{Ms} + 19.9$$

(Davies and Brune, 1971), or

$$(2) \quad \mathrm{LOG}_{10}\ \mathrm{Mo} = 3/2 * \mathrm{Ms} + 15.5$$

(Kanamori and Anderson, 1973). Figure two of Kanamori and Anderson shows the empirical relationship between Ms and LOG Mo, giving the proportional relationships involved. From this figure the constant of proportionality (15.5) can be derived.

Once the moment is figured the displacement can be calculated from (3):

$$(3) \quad u = \frac{1}{U * A} * \mathrm{Mo},$$

where u is the displacement in centimeters, U is the constant rigidity ($-3.3 * 10^{11}$ dyne/centimeters^{-2}) (Davies and Brune, 1971), A is the slip face area, and Mo is the moment sum.

As Ms is not given for all bulletin reported earthquakes, and because of the scantiness of data in the Scotia Sea region, a method for producing an estimate of Ms from the bulletin data was needed. Based on the knowledge that the number of stations reporting an earthquake was an approximate measure of the energy of an earthquake (post WWSSN establishment)(S. Stein and K. Fujita, personal communications), an empirical relationship between the number of stations reporting an earthquake in the ISC bulletin and listed Ms was developed. In the ISC bulletins Ms is reported from NEIS sorces, and to develop the relationship 72 Ms reporting earthquakes were used from the period 1971 - 1978, ranging from Ms of 4.4 to 7.1, from 21 to 334 stations, all from the Scotia Sea area. A straight line approximation was produced, having an approximation coefficient of .81. The general formula produced for this empirical relationship is:

(4) $Ms = .00865 * S + 4.57$

where S is the number of stations reporting. Substituting into the moment formula (2), and solving for Mo, give:

(5) Mo = 10 ** 3/2 * (.00865 * S + 4.57) + 15.5

or, reducing,

(6) Mo = 10 ** .1030 * S + 22.36 .

Using (6), the possibility that there is an actual difference in seismic subduction rates from north to south in the South Sandwich arc was investigated. Noting the intersection of the fracture zone at 58S with the subduction zone divides the zone into two age regions (50 - 60 million year old ocean crust north of 58S and 25 - 30 million year old ocean crust south of 58S (Brett, 1977)), calculations were done separately for the group north and the group south of 58S. Also, the edge seismicity of the north and south ends of the subduction added to that produced by subduction in these areas, so the data were limited to within a half degree of the supposed boundaries (the north group being from 55.6S to 58.0S, the south group being from 58.0S to 59.6S). Using the lengths from above, and using a dip of 60 degrees for the arc (Brett, 1977), the area A of the slip face was calculated assuming a maximum depth of focus of 33 kilometers (Rogers, 1981), and the rates u was calculated from (3) to be .9 centimeters per year for the north, and .6 centimeters per year for the south. The seismic moment for the north was calculated at 2.54 E 25 dyne centimeter/year, and for the south was calculated at 1.06 E 25 dyne centimeter/year.

Although the rates may be innacurate, even for the seismic subduction rate, it does show a 3:2 ratio of energy release between the north and south parts of the arc. Consequences of that are that either the South America - Antarctic spreading ridges are spreading unevenly, with the southern one (younger crust being subducted) having 2/3 the spreading rate of the northern ridge (older crust being subducted), or that the southern part of the subducting slab is more decoupled from the the overriding slab than the north part.

Variation in the back arc spreading of the magnitude necessary for this is not seen (Barker, 1972), nor does the this author wish to imply that back arc spreading drives subduction. If the fist hypothesis is true, an active seismic zone along or near 58S would be seen, with left lateral strike-slip motion being evidenced. A nearby, previously unnoticed strike-slip fault boundary along 59.5S has been observed but the sense of motion along it is reversed (i.e., right-lateral) and furthermore is on a feature distinctly separate to the fracture zone at 58S.

Support for this hypothesis comes from the change in character of intermediate depth earthquakes at 58S latitude from downdip compression south of, and downdip extension north of 58S (Forsyth, 1975; Brett, 1977). This could support the hypothesis of faster subduction in the north than the south, as downdip extension in the north shows the slab being pulled down, and down dip compression in the south shows the slab subduction being resisted.

The second hypothesis, that of decoupling, is standardly accepeted (Brett, 1977). The older slab, the north, because it is less bouyant, should be subducting at a faster rate than the south. But since the north slab is welded to the south slab, the bouyant south slab holds it back from subducting faster, and vice versa, the south slab is pulled down faster (Brett, 1977). Being forced to subduct at identical rates, and since the south slab is younger than the north and easier to deform, the seismicity of the south can be expected to be weaker and the deformation more likely to be taken up aseismically.

A third hypothesis is also possible, the hypothesis being that the southern, newer oceanic crust is being subducted faster than the northern, older ocean crust. First, the ususal theory to explain the lack of deep seismicity in the South Sandwich arc is the newness of the subduction zone (Brett, 1977). However, the observed earthquakes are not as deep as would be expected for an arc of this young age (Brett, 1977). Also, more recent studies show the existance of the arc before the onset of the current back arc spreading, back to at least 26 million years ago (Hill and Barker, 1980). This leads to the supposition that the slab (as it is sinking) does extend to below 160 kilometers in depth, and is near gravitational equilibrium with the surrounding mantle at these depths (no observed earthquakes means no sudden stress release). Other slabs of approximately this length and age of slab being subducted (Peru, Central Chile) also show the same style of intermediate depth earthquakes as the northern part of the South Sandwich subduction zone (tensile - extensional), and with subduction occuring at similar rates of speed (8 - 10 centimeters/year) (Fujita and Kanamori, 1981). The problem is then, "why does the south part of the South Sandwich subduction zone show 100% compressive intermediate depth earthquakes?"

This could be explained by the nearness of the spreading ridge to the subduction zone and the extreme newness of the crust being subducted (the South Sandwich subduction zone is subducting the youngest ocean crust of any active subduction zone (Fujita and Kanamori, 1981)). As deep earthquakes are not seen in the south either, then as in the north the slab must be in gravitational equilibrium with the surrounding mantle at depth, giving no reason for suspecting a resistance to subduction at depth. At intermediate depths, the compressive mechanisms could be resulting from resistance to subduction arising from more rapid subduction then can be compensated at intermediate depths, and the 3:2 energy release ratio seen between north and south can be explained simply by the lower viscosity of the hotter, younger ocean crust leading to more energy taken up by aseismic strain than by fracture strain. The extra rate differential between the crust north of 59.5S and south of 59.5S could be explained by a ridge jump that occurs just to the north of this, providing for a spreading ridge closer to the subduction zone on the south than on the north, and thus possibly allowing for ridge push to become important in this subduction process, speeding up the rate of subduction.

Other rate ratio calculations were done on the many strike-slip faults around the Scotia Sea. The first rate considered is the rate of slip along the South Scotia Ridge rate verses that of the slip rate along the north boundary of the Scotia Sea. Using the above method, the ratio of energy release per unit length between the north and south boundaries was 25:60. Also, the ratio found between the Shackleton and Aluk Ridge energy per unit length was 9:2, and between the Shackleton and South Scotia Ridge was 9:6. If the total rate of slip between the Antarctic and South

American plates is 1.6 centimeters per year (Minster and Jordan, 1978), the calculated slip rate on the north Scotia Sea boundary is .46 centimeters per year, and that on the South Scotia Ridge is 1.14 centimeters per year.

The slip rate on the Shackleton fracture zone, calculated from the ratio to the slip rate on the South Scotia Ridge, would then be 1.71 centimeters per year. If the angle the Shackleton fracture zone makes with the generalized regional stress directions given in Minster and Jordan (1978) is correct, then the component of motion of the Shackleton fracture zone in the direction of regional stress is 1.3 centimeters per year. This is in rough agreement with the slip rate along the South Scotia Ridge (which is along the direction of regional stress).

The rate of slip along the north boundary of the Scotia Sea is only 30 to 40% that of the Shackleton and South Scotia Ridge, and takes up only 30% of the total South American - Antarctic slip motion. The slip rate for the off Shackleton seismic zone is even less, showing that it and the north boundary are different in tectonic style in this area also.

Seismicity Comparisons

Comparisons to other similar (seismically) areas can put the observed seismicity and focal mechanisms of the Scotia Sea into a better perspective (figure 16). The seismotectonics of the Scotia Sea and its surroundings can be analyzed in terms of the area as a back arc basin (Hill and Barker, 1980), an area of intraplate seismicity (Forsyth, 1975), as one of interplate deformation, or as intramarginal deformation.

When considering the Scotia Sea as a complex maginal basin the obvious comparison seismically is to the Caribbean Sea. Similarities are that in both a westward dipping Atlantic plate subducts beneath an eastward moving oceanic basin, bounded on both north and south by strike-slip margins (Molnar and Sykes, 1969). The boundary of the Caribbean on the south is much more diffuse than any in the Scotia Sea, but like the north boundary of the Scotia Sea is mostly a continental boundary (Molnar and Sykes, 1969). In activity it is as active as the Scotia Sea's south boundary, with no magnitude 7 or greater earthquakes, and four magnitude 6 - 7 earthquakes in the period 1950 - 1964 (versus no magnitude 7 or greater and three magnitude 6 - 7 earthquakes for the South Scotia Ridge in the period 1960 - 1980). The north strike-slip boundary of the Caribbean is more active and is tied to active spreading in the Cayman trough. In the Cayman trough, there was one magnitude 7 and four magnitude 6 - 7 strike-slip earthquakes in the period 1950 - 1964 (Molnar and Sykes, 1969), much greater than on any of the Scotia Sea plate boundaries.

In the Caribbean, however, the subduction rate is slow, only 2 centimeters per year, and the crust being overridden is much older (90 million years old) (Stein et al. , 1982). Studies of the seismicity show that the subducted plate is entirely decoupled with respect to thrusting and typical suduction zone events (Stein et al., 1982). In the Caribbean subduction there are no major and few minor thrust events seen, and most of the earthquakes being of the normal faulting or strike-slip faulting varieties (Stein et al., 1982). The South Sandwich subduction zone, although said to be partially decoupled (Brett, 1977), still has many thrusting earthquakes throughout the shallow thrust zone (Forsyth, 1975).

Another possibility for the Scotia area is that its seismicity may be intraplate - that it is a marginal basin undergoing intraplate deformation. Intra-marginal-basin earthquakes tend to be small, the largest seen being Ms = 5.6, Mb = 5.9 (Wang et al., 1979), in the South China Sea. These intraplate events usually are thrust events, dissimilar to the many strike-slip events seen in the Scotia

Sea, but nevertheless similar to some events seen in the eastern part of the north boundary and the earthquakes observed north of the outer rise region of the arc - trench. The pattern of regional stress cannot be found from intraplate earthquake focal mechanisms, and the relation between regional stress and the maximum principal stress of an earthquake is such that the quadrant containing the maximum principle stress must be the quadrant containing the regional stress also, and could be as far as 90 degrees away (McKenzie, 1969). With this in mind, the principal stress directions of the above events are found to lie in the quadrants of the predicted regional stress.

The last possibilities to be considered for some of the boudaries of the Scotia Sea are whether they represent major intraplate (or interplate) zones of weakness. The areas of comparison will be to the 90 East Ridge, an intraplate zone of weakness, and the Macquarie Ridge, an interplate zone of weakness.

The 90 East Ridge has a mixture of strike-slip earthquakes and thrust earthquakes with small strike-slip components. The seismic moments of the five major earthquakes evaluated on this feature sum between 650 E 25 dyne centimeters and 1050 E 25 dyne centimeters (Stein and Okal, 1978), two orders of magnitude larger than the sum of moments of the north and South Scotia Ridge boundaries combined. Similarities observed between the two areas include the blockyness of the 90 East Ridge, the South Scotia Ridge and the North Scotia Ridge. In the case of the 90 East Ridge, the blockyness is explained as expression of the lateral movement that has taken place along the ridge. Another similarity is the scatter of earthquakes. In the case of the 90 East Ridge, not all earthquakes, even the strike-slip mechanism quakes, take place on the ridge proper. This is similar to seismic patterns seen in the Shackleton fracture zone area and the north boundary of the Scotia Sea.

The Macquarie Ridge is a part of the plate boundary system that divides the Australian and Pacific plates. The boundary is interesting in that it lies within four degrees of the relative pole of motion of the two plates, as calculated in the RM1 and RM2 plate motion models (Minster and Jordan, 1978). Focal mechanisms indicate thrusting predominates along the north part of the ridge, with a Benioff zone in the extreme north along the Puysygur Trench (Johnson and Molnar, 1972). Strike-slip motion along the ridge proper predominates (Denham, 1975; Johnson and Molnar, 1972), and normal faulting predominates in the south along the Hjort Trench, which is a possible spreading center (Johnson and Molnar, 1972; Hayes and Talwani, 1977). The whole ridge area shows 7 earthquakes with 200 or more

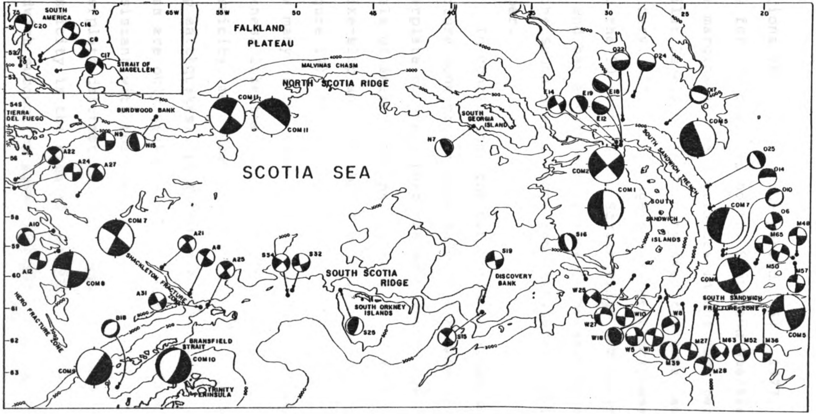


Figure 16 - Focal Mechanisms in the Scotia Sea Area

stations reporting in the period 1964 - 1977, as compared to five for the combined north, South and Shackleton fracture zone margins of the Scotia Sea in the same period, showing similar levels of seismicity over the same length of plate boundary. Also, the ridge shows the blockyness in bathymetry that the 90 East, South Scotia Ridge and North Scotia Ridge do, and has a very narrow zone of seismicity similar to that of the South Scotia Ridge and Shackleton fracture zone proper.

In conclusion, the South Scotia Ridge and Shackleton fracture zone proper show many of the same properties of an interplate boundary that the Macquarie Ridge does (similar levels of seismicity, narrow zone of seismicity, mostly strike-slip and few thrust earthquakes, blocky ridges) (figure 17). The Aluk Ridge and north Scotia seismic zones show many of the same properties as an intraplate zone of weakness like that of the 90 East Ridge (diffuse zone of seismicity, more nearly equal numbers of thrust and strike slip earthquakes), plus both the north margin and Aluk Ridge areas are only weakly active (low energy output), more consistant with the idea of intraplate deformation than interplate deformation. The other major zone of intraplate seismicity is the area of the outer rise near the South Sandwich subduction zone, and northward. On the outer rise, normal faulting is exibited, as is expected. Away from the

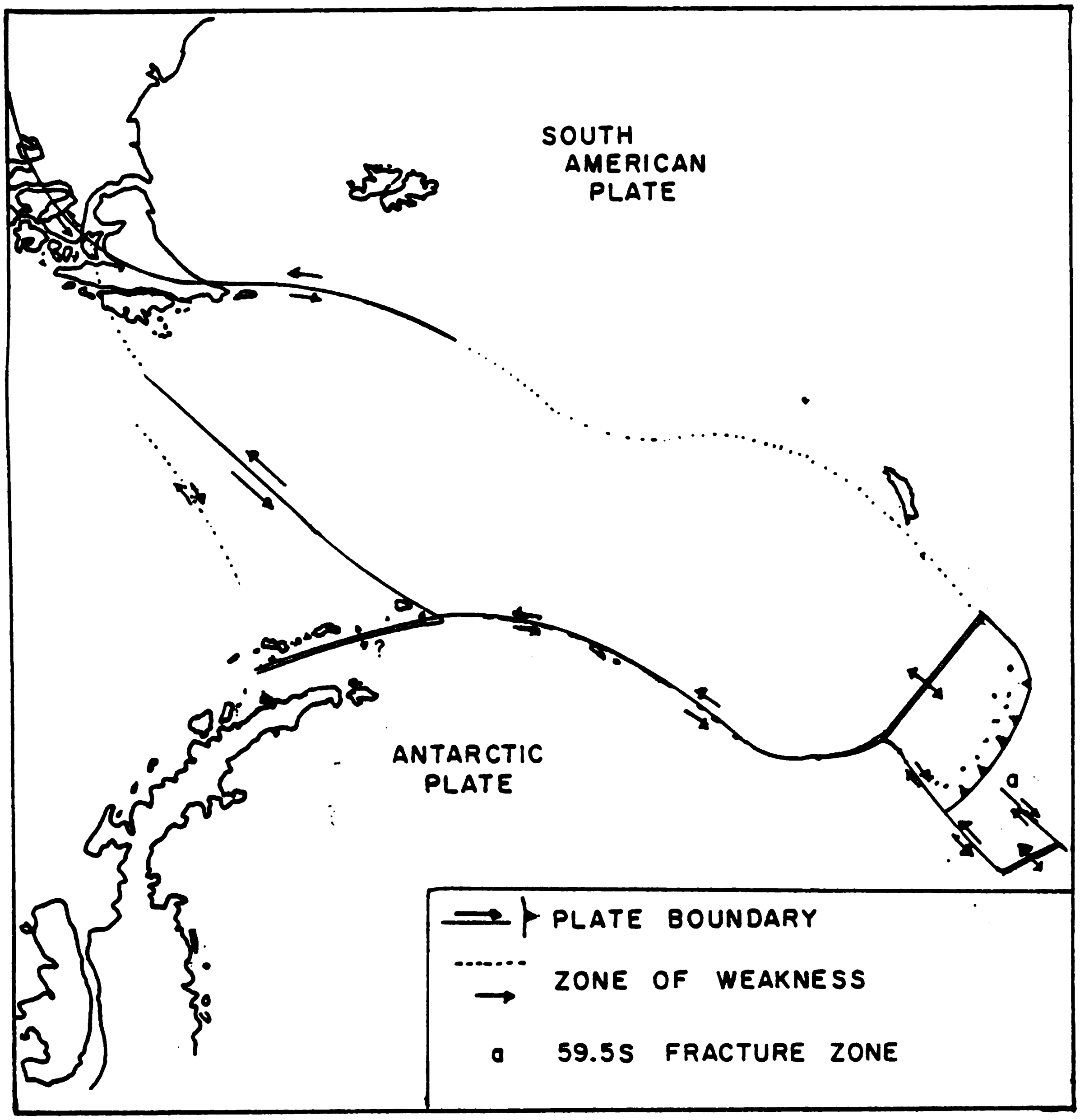
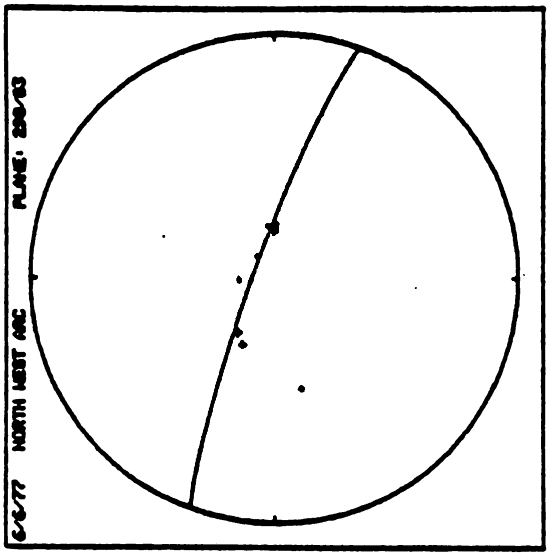


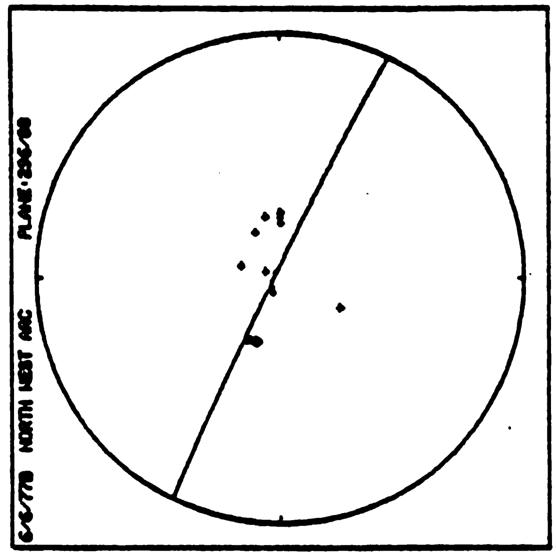
Figure 17 - Plate Boundaries in the Scotia Sea Area

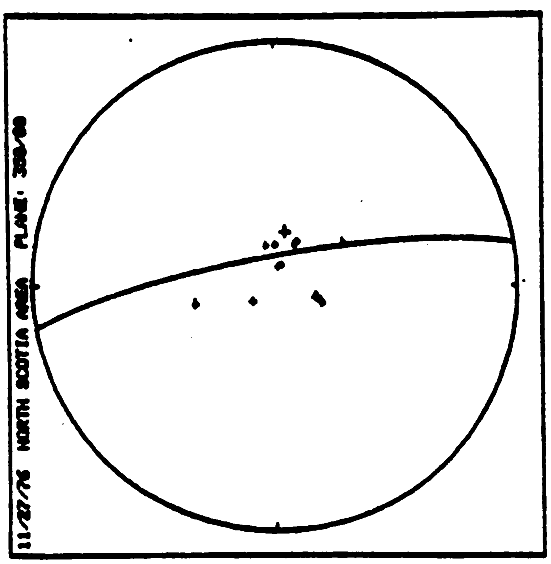
outer rise ambiguous dip-slip faulting is exibited which may be either intraplate compression due to regional interplate stress or vertical faulting due to downwarping of the oceanic crust north of the north end of the South Sandwich trench. Also examined was a new interplate boundary, the 59.5S fracture. This lies east of the subduction zone perpendicular in strike to the trench, and is an interoceanic strike-slip boundary defining a small plate lying between the Antarctic and South American plates, indicating that the extreme southern part of the subducting slab is subducting ocean crust faster than the subduction zone to the north of it. Reasons for faster subduction include the closeness of the spreading ridge to the subduction zone providing a large ridge push component to the slab.

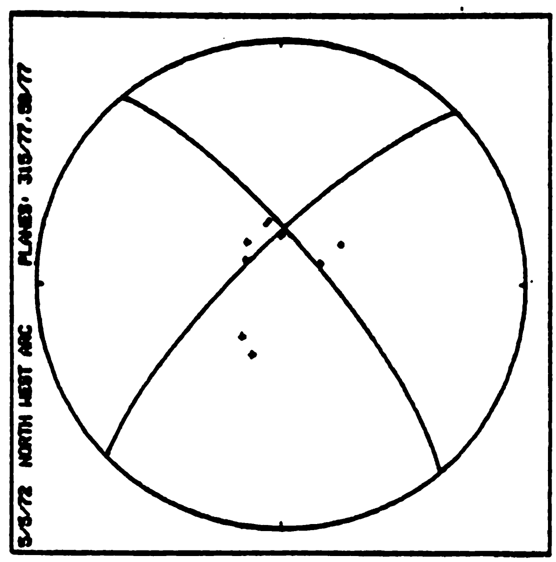
APPENDIX I

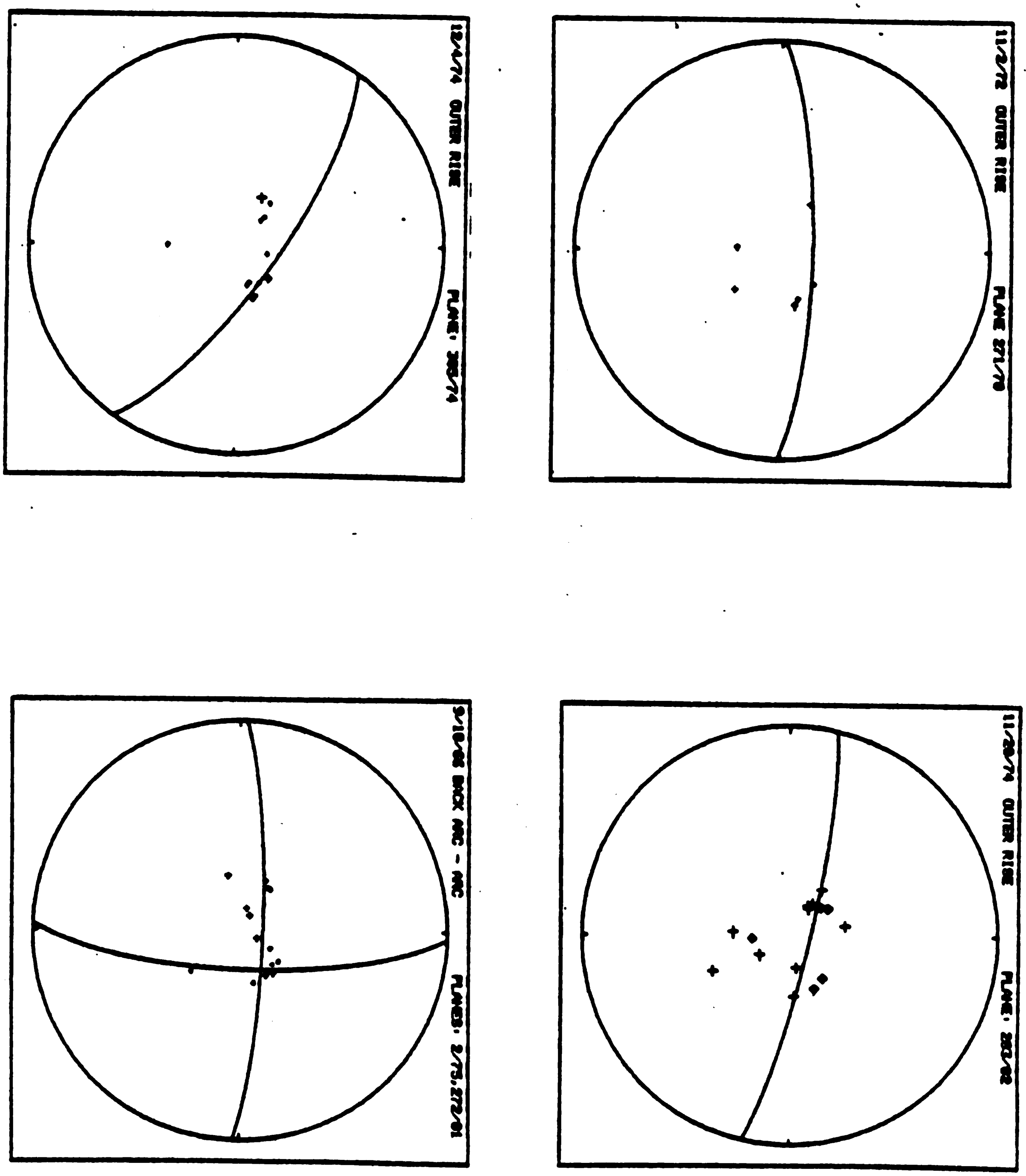
Focal Mechanisms of the Scotia Sea Area and South Chile

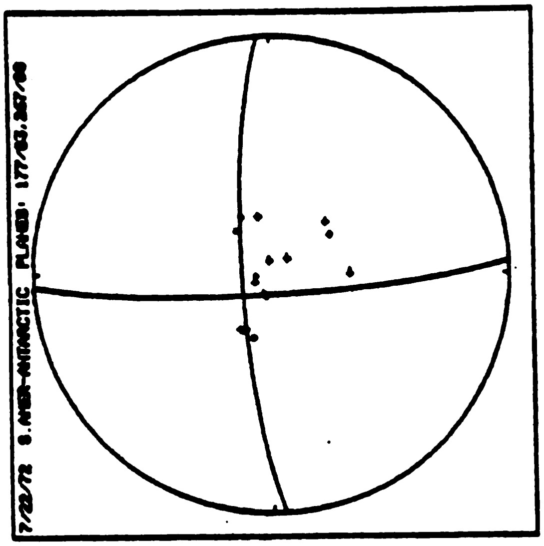

NORTH WEST ARC
PLANE:

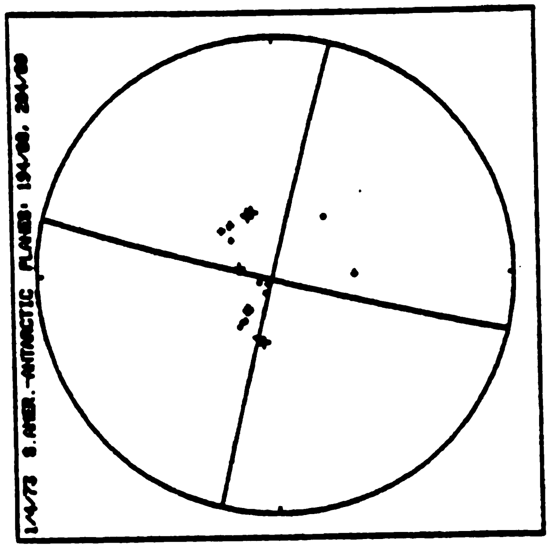

NORTH WEST ARC
PLANE:


11/27/76
NORTH SCOTIA AREA
PLANE:


NORTH WEST ARC
PLANES:


OUTER RISE
OUTER RISE
BACK ARC - ARC
OUTER RISE


S.AMER.-ANTARCTIC PLANES: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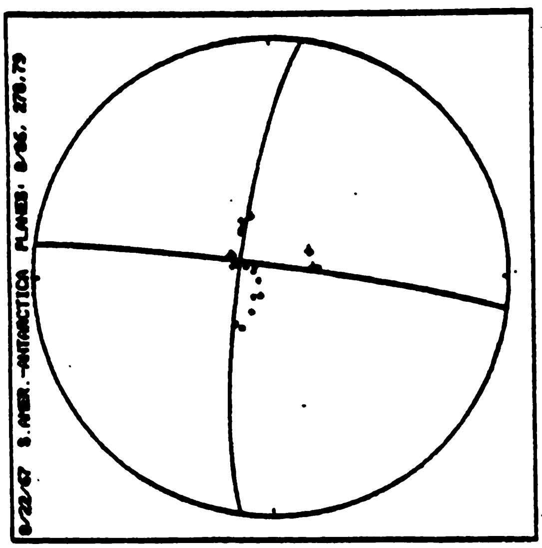
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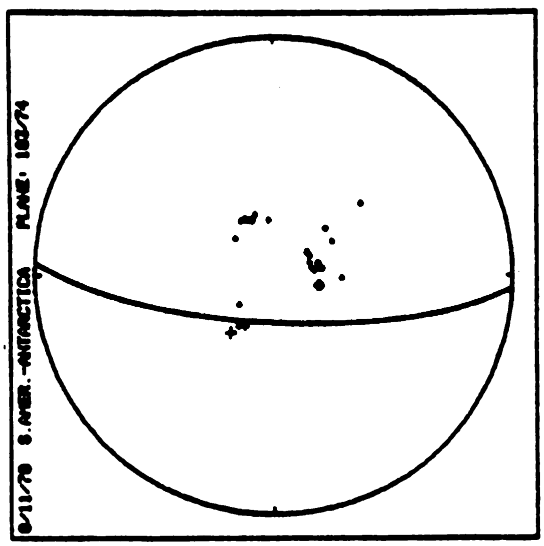
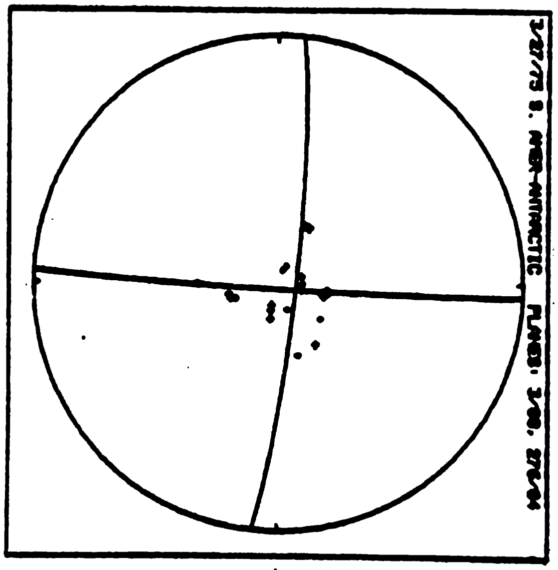
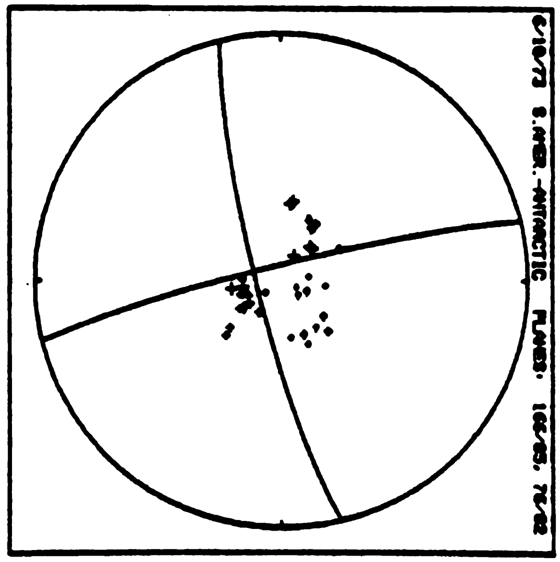
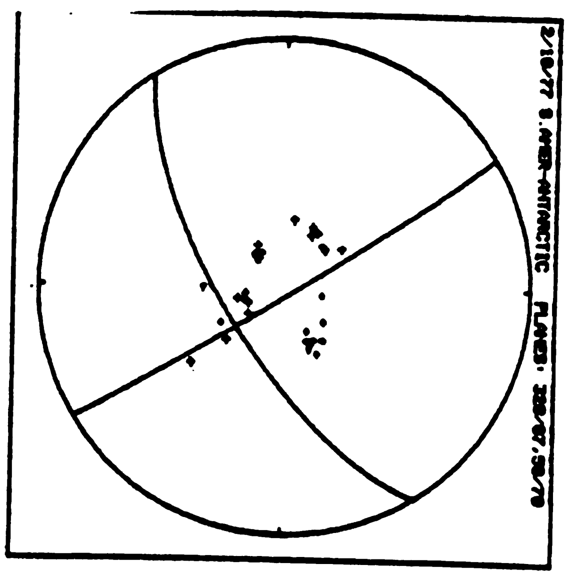

S.AMER.-ANTARCTICA PLANE:


S. AMER-ANTARCTIC PLANES:


6/10/73 S.AMER.-ANTARCTIC PLANES: 166/85, 76/82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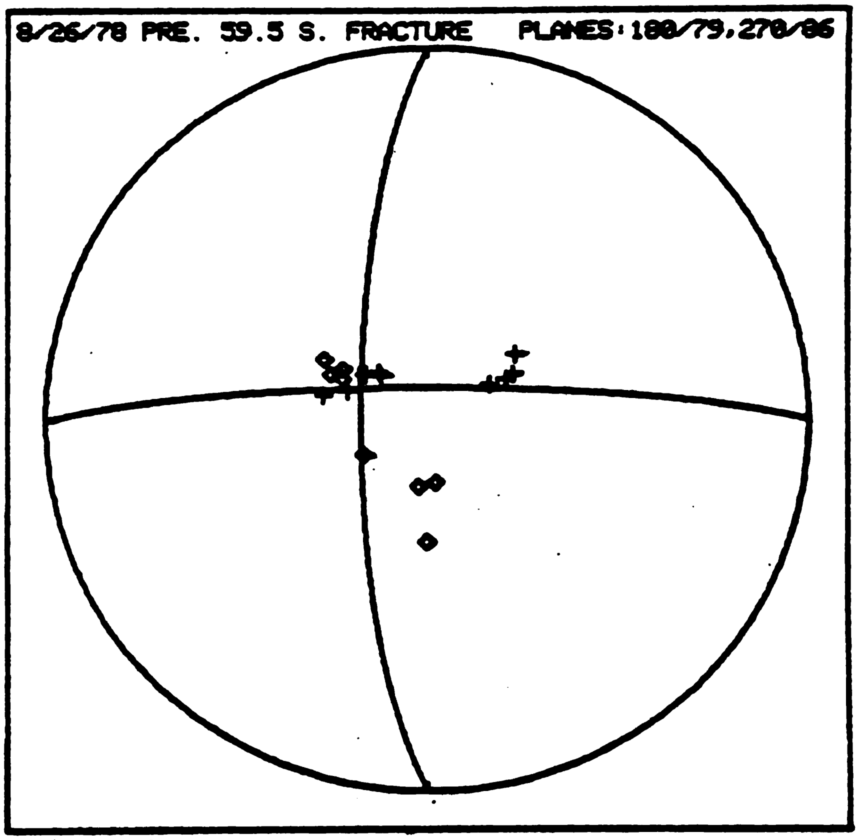
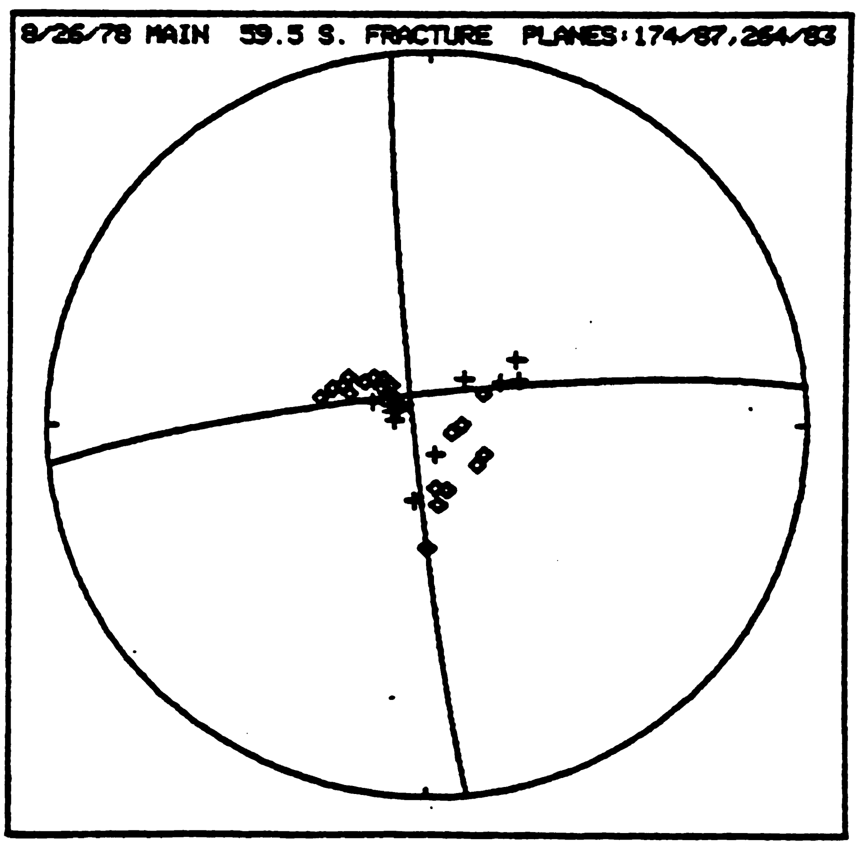
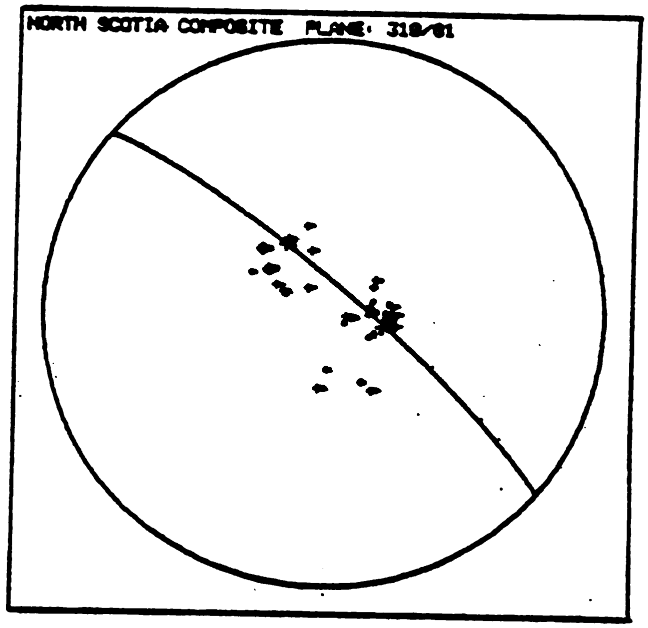
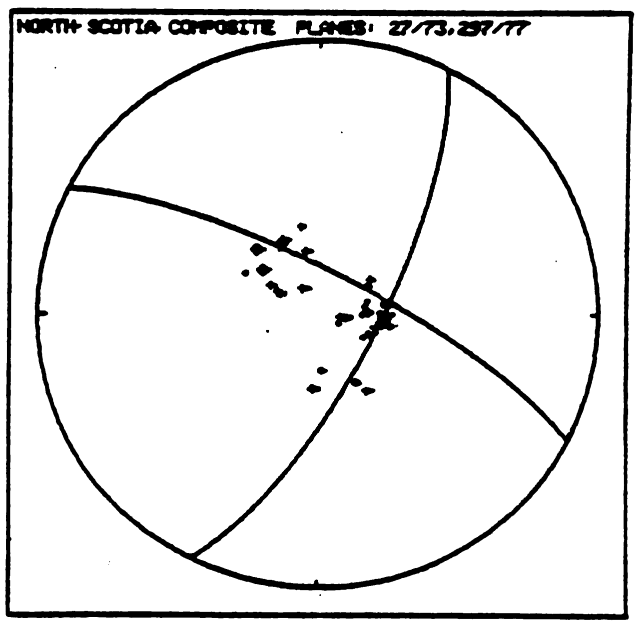

8/26/78 PRE. 59.5 S. FRACTURE PLANES:180/79,270/86

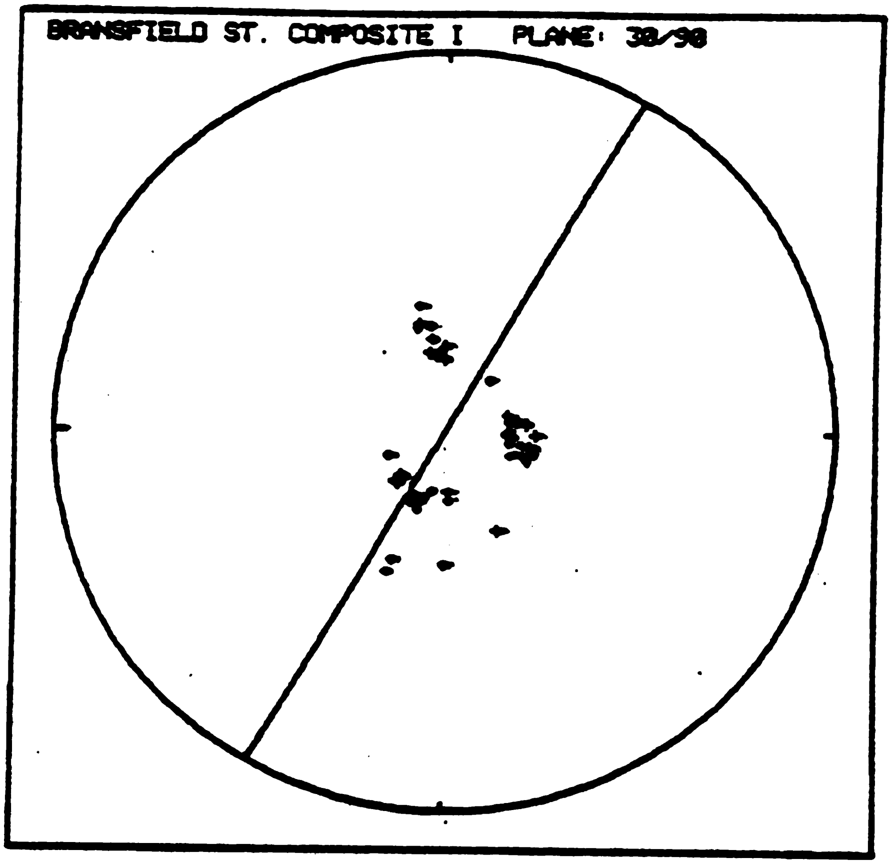

8/26/78 MAIN 59.5 S. FRACTURE PLANES:174/87,264/83

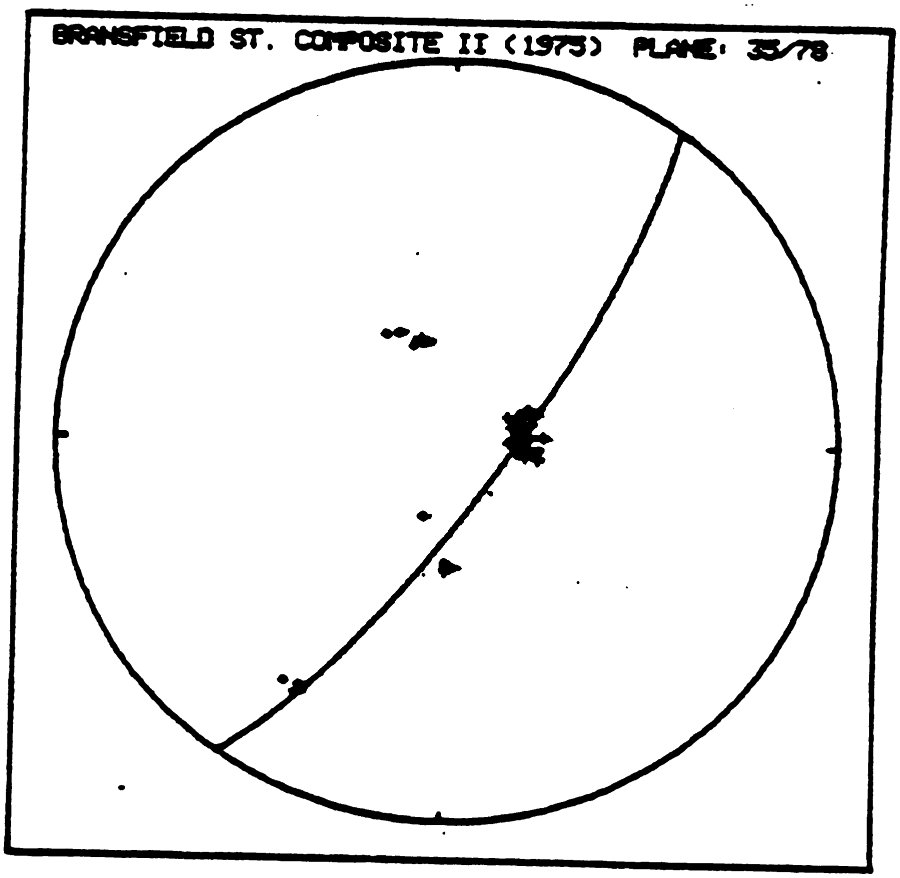
APPENDIX II

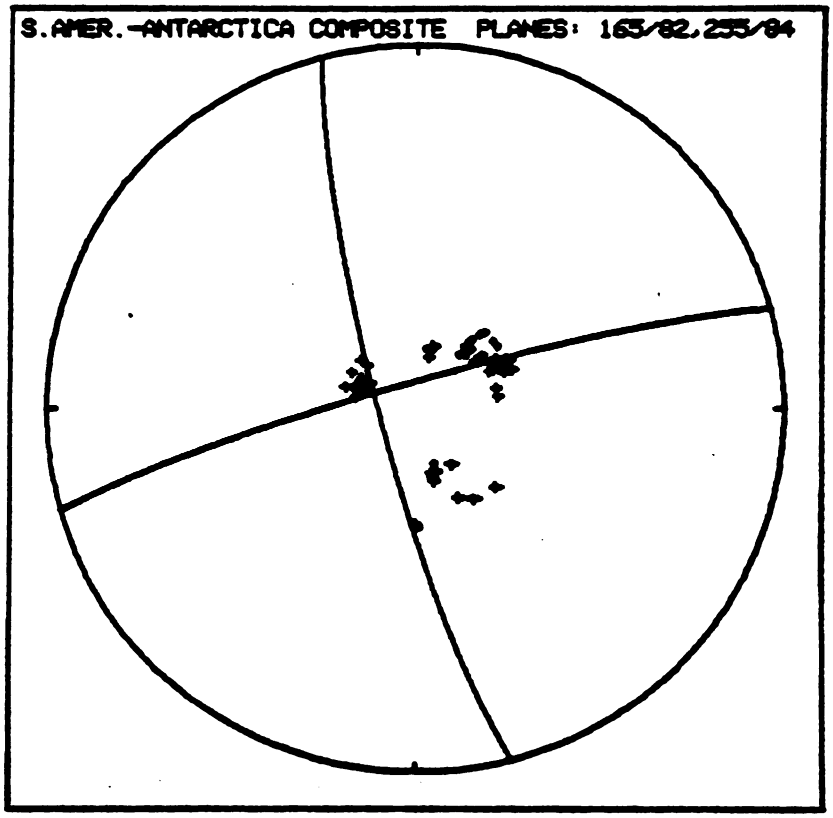
Composite Focal Mechanisms of the Scotia Sea Area

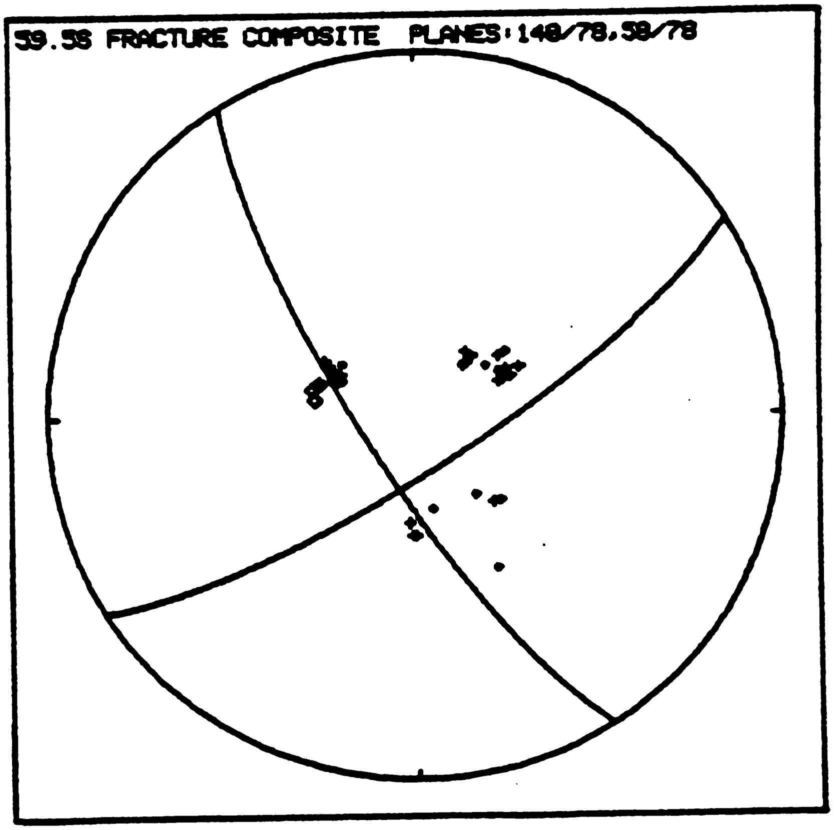

NORTH SCOTIA COMPOSITE PLANE: 310/81

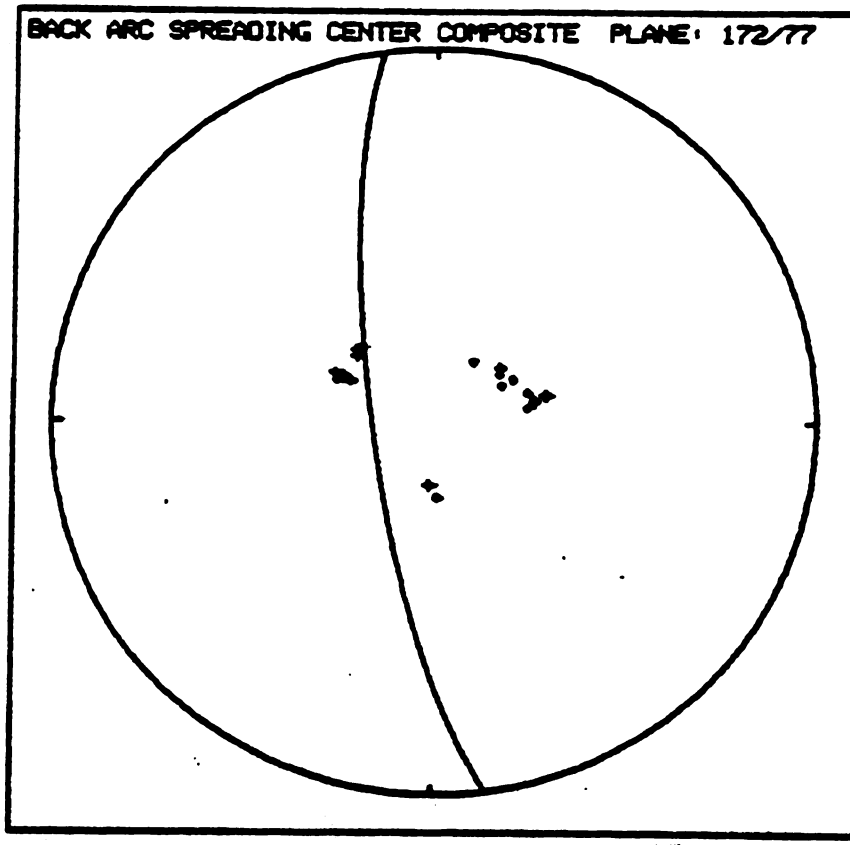

NORTH SCOTIA COMPOSITE PLANES: 27/73.297/77

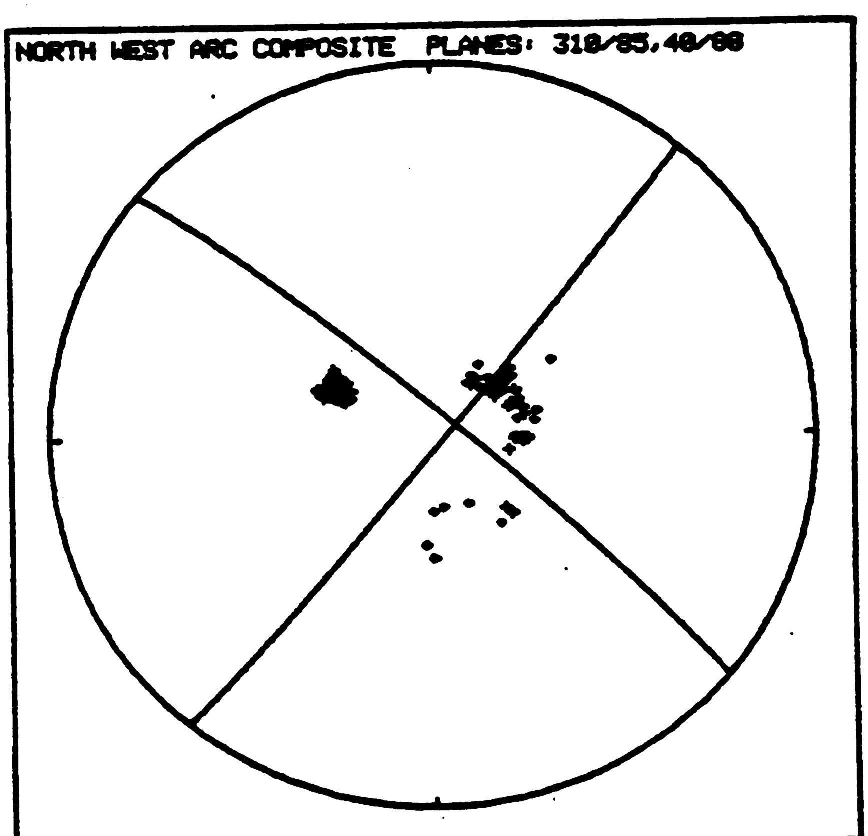

BRANSFIELD ST. COMPOSITE I PLANE: 38/90

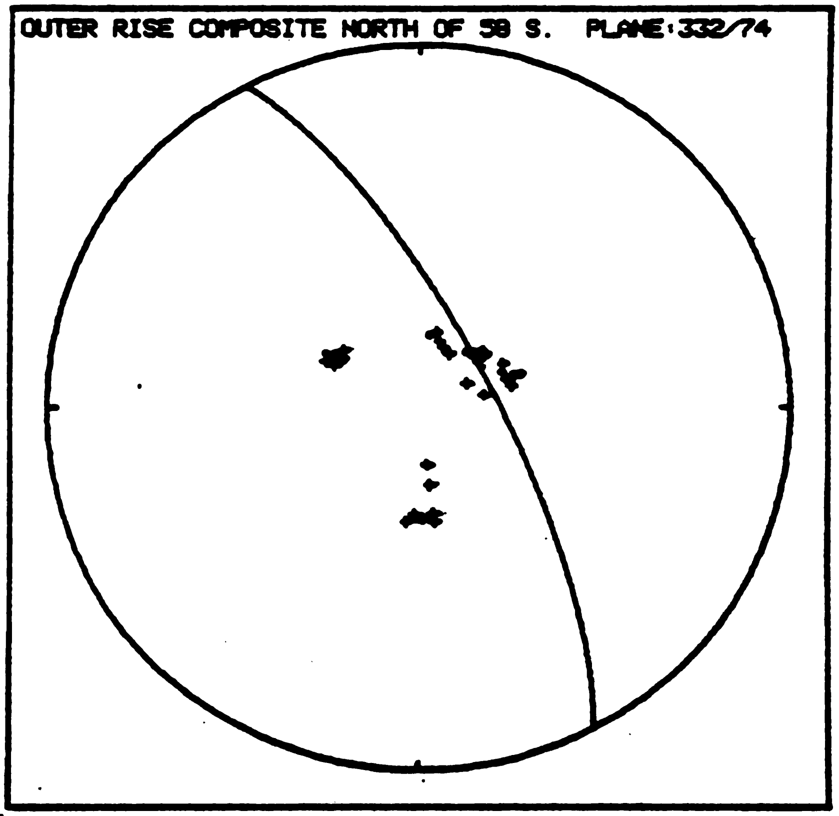

BRANSFIELD ST. COMPOSITE II (1975) PLANE: 35/78

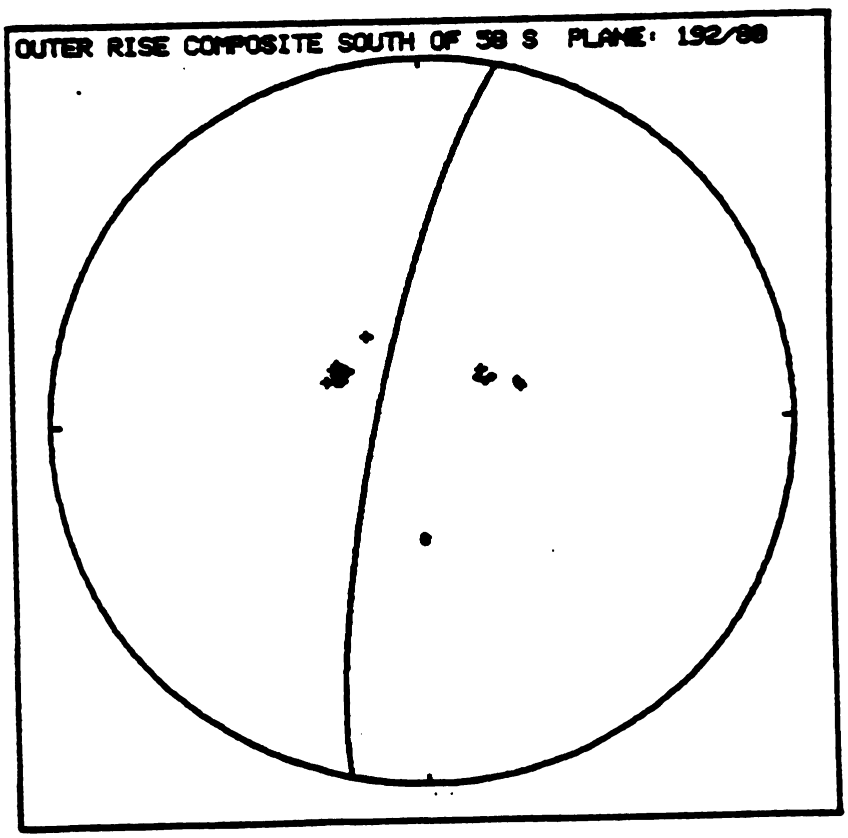

S.AMER.-ANTARCTICA COMPOSITE PLANES: 165/82,255/84


59.5S FRACTURE COMPOSITE PLANES:148/78,58/78


BACK ARC SPREADING CENTER COMPOSITE PLANE: 172/77


NORTH WEST ARC COMPOSITE PLANES: 310/85,40/88


OUTER RISE COMPOSITE NORTH OF 58 S. PLANE:332/74


OUTER RISE COMPOSITE SOUTH OF 58 S PLANE: 192/80

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