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Maps showing types and distribution of faults interpreted from seismic profiles in the St. George basin region, southern Bering Sea

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INTRODUCTION

Geologic studies in the St. George basin region have concentrated mainly on the structural evolution of the Beringian continental margin and the origin of the St. George basin (Scholl and others, 1966; Scholl and others, 1968; Scholl and Hopkins, 1969; Scholl and others, 1970; Pratt and others, 1972; Moore, 1973; Nelson and others, 1974; Scholl and others, 1975; Cooper and others, 1976; Marlow and others, 1976; Marlow and others, in press). This study focuses on faulting by describing the types and distribution of faults found in the area.

This is the first of a series of reports on the geological environment of this region. Data in the process of being analyzed include the distribution of sediments, geochemistry of surface sediments (both organic and inorganic) and detailed bathymetry.

The St. George basin area can be broadly subdivided into four major physiographical provinces: outer continental shelf, continental slope, Pribilof ridge, and the Bering and Pribilof Canyons (Figure 1 and Plate 1, figure A). The outer continental shelf is a broad, flat region that has a gradient of 1:2000 (0.03°) between the 100 m isobath and the shelf break at 170 m. The shelf break persists at about 170 $\pm$ 2 m depth along those parts of the margin that are not cut by the large submarine canyons. The Pribilof ridge is a prominent northwest-southeast-trending topographic high that is capped by the Pribilof Islands. It has a relatively smooth surface with at least one wave-cut terrace that may be Pleistocene in age. The ridge plunges into the subsurface at about $56^{\circ}31"$N, $168^{\circ}35"$W, but can be followed in the subsurface on seismic data to 56°N, $165^{\circ}40'$W. The continental slope abruptly drops away from the shelf break in the northwestern part of the area where gradients are about 1:20 (3°). Towards the southeast, however, the gradient decreases to about 1:40 (1.4°). The continental slope is characterized by hummocky topography, scarps, and is incised by numerous canyons.

The geology of the southeastern segment of the Beringian continental margin is briefly described by Scholl and others (1968) who distinguished two major acoustic units that overlie a seaward-thinning crust. An upper low-velocity, semi-consolidated unit, the "main layered sequence", unconformably overlies a lithified second unit that corresponds to acoustic basement on low frequency, seismic-reflection profiles. The essentially flat-lying upper unit ranges in thickness from 500 m to several thousand meters and probably is mostly of Cenozoic age (Creager, Scholl, and others, 1973; Scholl and others, in press). The lower acoustic unit, which is tightly folded beneath the outer continental shelf probably represents Upper Cretaceous sediments (Scholl and others, 1966, 1968; Hopkins and others, 1969).

The St. George basin is a deep subsurface graben whose long axis is parallel to the present continental margin. The basin, according to Marlow and others (1976), has an area of approximately 1000 km^2 (300 km long and in places up to 50 km wide) and a volume of at least 56,000 km^3. Marlow and others (in press) speculate that after subduction jumped from the Bering Sea to the south, forming the Aleutian ridge, tectonic deactivation occurred along the Beringian continental margin. Since then, the outer shelf has undergone extensional rifting and regional subsidence. Differential rifting and subsidence have resulted in the formation of a series of basement ridges and basins in the area; the basins subsequently have been filled with sediment.

SOURCES AND METHODS

The data used to map the distribution of faults and areas of potentially unstable sediment masses are from the following seismic-reflection equipment: (1) 3.5 kHz; (2) kHz (Uniboom source); (3) single-channel seismic reflection (60 KJ to 160 KJ sparker and up to 1300 in^3 air gun sources); and (4) 24-channel multichannel equipment using a 1300 in^3 airgun array. The various types of data and the cruises are shown in Table 1 and Plate 2, figure E which shows the appropriate tracklines. Approximately 7,000 km each of 3.5 kHz, Uniboom, and single-channel seismic-reflection data and about 700 km of multichannel seismic-reflection profiles were studied.

Table 1. Cruises and types of seismic-reflection data.

		Date Type				
Ship	Cruise	High Resolution		Low Resolution		
		3,5 kHz	Uniboom 2.5	single channel	single channel	multi-channel
R/V SEA SOUNDER	S4-76	X	X		X	
R/V LEE	L5-76	X	X	x	X	
R/V LEE	BERS-75-Xa	X	X			X
R/V STORIS	ST-69				X	

Navigation was by integrated Loran C and satellite for cruises of the R/V SEA SOUNDER and R/V LEE and by satellite for R/V STORIS. In addition, the R/V LEE utilize doppler sonar integrated into the navigation system. The integrated navigation systems have nominal position accuracies of ± 200 m or better, whereas the satellite system of the R/V STORIS has position accuracies of ± 500 m or better.

The distribution of faults was compiled by studying the profiles in order of low to high frequency (increasing resolution). First, features found on the multichannel data were plotted, followed by data from single channel, then 2.5 kHz Uniboom, and finally 3.5 kHz profiles. The major advantage of this technique is that large-scale features are initially pin-pointed and, subsequently, their geometries and effects are refined at increasingly smaller scales.

In general, the quality of the 3.5 kHz data is only fair, but the 2.5 kHz Uniboom data are fair to good and the low-resolution seismic-reflection data are fair to excellent. The 3.5 kHz system generally penetrated only to the first subbottom reflector (0.005 sec; approximately 4 m), but in a few places it penetrated to 0.05 sec (approximately 35 m). The 2.5 kHz Uniboom system typically penetrated to 0.05 sec or less. The single-channel seismic-reflection profiling systems penetrated to a maximum of about 2.0 sec in deep water and multi-channel system was able to penetrate as much as 5.5 sec over the St. George basin (Marlow and others, in press).

Factors which affect the quality of the seismic data can be grouped in two broad categories: (1) the types of seismic systems used and their environments, and (2) the surface and subsurface geology. The environment of the seismic system includes the sea-state at the time of recording, ambient acoustic interference generated by the vessel, depth of water, and watchstander overseeing the system. The first two factors affect the high-resolution systems much more than the low-resolution systems. Sea-state conditions during which most data were collected ranged between calm and Force 8, but were typically between Forces 1 and 4. Rough sea-states result in the decoupling of hydrophones and/or transducers from the water column, thus seriously reducing the quality of high-resolution records. Ambient acoustic interference generated by the vessel adds further to the noise level on all the data. The depth of water affects the high- and low-resolution systems in opposite ways. On the lower-resolution single-channel systems, shallow water depths influence the records by producing a first harmonic (multiple) that on many records obliterates the signals beneath it. As the water depth increases, the interference by the first multiple is at deeper levels on the records, thus allowing more signals to be recorded. The high-resolution systems, however, performed well in shallow water because of the high repetition rates of the outgoing singnals (generally 1/4 to 1 sec), but they did not perform well in deep water because of their relatively low power output. Reverberations create a "ringing" that also tends to mask out some signals.

Despite the weaknesses of the various systems and because of the coverage of the area and the large amount of good quality data collected, we feel that the data are more than adequate to interpret the regional surface and near-surface geology.

CLASSIFICATION OF FAULTS

In this study, we classify faults by the seismic system that resolved the feature. The resolutions of the seismic systems (Table 2) were calculated using the velocity of sound in water and by following the procedure of Moore (1972) who showed that the resolution of seismic-reflection systems is between 0.25 and 0.75 the wavelength of the source.

Table 2. Ranges of resolution for seismic systems.

Approximate Peak Frequency	Range of Minimum Resolution (m)
100 Hz	3.2 to 11.2
2.5 kHz	0.15 to 0.5
3.5 kHz	0.1 to 0.3

However, as we noted above, the actual resolution of a feature is not only a function of the outgoing frequencies but also is affected by the environments of the system (e.g., sea-state, depth of water, acoustic interference, watchstander) and the surface and subsurface geology. There is a gap in the resolving range of our systems between about 0.5 m and 4 m which suggests that features with thicknesses or offsets in that range would not necessarily be resolved.

Our studies have concentrated on faults within the main-layered sequence. The faults are classified as surface, minor, and major faults. Surface faults are those that offset the surface of the sea floor regardless of which seismic system recorded them (Plate 1 Figure B). They generally offset the sea floor no more than a few meters. A minor fault is one observed on Uniboom and/or 3.5 kHz records, but not on single- or multichannel seismic-reflection profiles. This class of fault typically has displacements of less than 0.006 sec (5 m), and most are near-surface but do not break the sea floor (Plate 1, Figure C). In places, sediment can be seen draping over what was a Pleistocene surface fault (Plat 1, Figure C). Major faults are those seen on multi-channel and single-channel seismic-reflection profiles (Plate 1, Figure D). They generally show growth features (increasing offsets with depth) and in places they offset acoustic basement. Boundary faults are a subclass of major faults that mark boundaries of the major structural elements.

DISTRIBUTION OF FAULTS

The distribution of faults is given in Plate 2, Figures A, B, and C. The symbols used in these figures are squares, triangles, and circles and the senseof displacement is indicated by shading on either side of a horizontal line within the symbols. No fault trends should be interpreted from the symbols themselves.

Boundary faults clearly delineate the St. George basin and the Pribilof ridge that bifurcates the basin in the subsurface (Plate 1, B). These subsurface faults typically have a normal sense of displacement, occur in groups, show growth features with depth, in many places cut nearly all of the sediment section, at places offset acoustic basement, and in rare places offset the sea floor. Offsets greater than 0.08 sec (60 m) occur in the central region of the St. George basin. These faults are the only ones connected to form linear fault zones in Figures 7 and 8 because they clearly define major structural features.

Major faults (those that are not boundary faults) occur principally within the confines of the St. George basin with a few scattered in the Amak basin that lies to the southwest (Plate 2, Figure B). They seem to decrease in number near the Pribilof Islands. These subsurface faults show displacements that generally are less than the larger boundary faults. They do not always show the same sense of offset as the adjacent boundary faults, which suggests that the tectonics involved are more complicated that just simple subsidence. Faults found on NE-SW ship tracks (perpendicular to the long axis of the basin) greatly outnumber those observed on NW-SE tracks, which indicates that the vast majority of major faults have a NW-SE trend probably paralleling the axis of the St. George basin. However, because of the large number of faults and the 30 to 50 km trackline spacing, we have not connected any of these faults into trends or zones.

Surface faults tend to be more abundant along the outer margins of the St. George basin and along the Pribilof ridge (Plate 2, Figure B). Most can be traced from high-resolution to low-resolution records, thereby indicating that most surface faults are tied to major faults and boundary faults. Only one surface fault was observed in Amak basin.

Minor subsurface faults occur throughout the region but, similar to the other classes of faults, are concentrated in the mid-St. George basin away from the Pribilof ridge and occur with greater frequency south of the ridge than north (Plate 2, Figure C). The great majority of minor faults do not offset the sediment surface. Few minor faults occur over the Amak basin, suggesting that the basin is a flexure rather than fault controlled. Just as with major faults, many more minor faults were encountered on NE-SW tracklines than on NW-SE lines, which suggests that most minor faults trend NW-SE, roughly parallel to the boundary faults and to the axis of the St. George basin. Again, no attempt was made to correlate minor faults between tracks because of the track spacing. Most minor faults have offsets of less than 0.006 sec (5 m) and almost all affect the top 0.005 sec (approximately 4 m) of sediment section. Preliminary results from studies of diatoms in 50 gravity cores that range up to 2 m in length show that none of the sediment recovered is older than 260,000 yrs; all are within the Denticula seminae zone (John Barron, pers, commun., 1976). If we assume that a 2 m core just penetrated the entire Denticula seminae zone, then there is a minimum sediment accumulation rate of about 0.8 $cm/10^3$ yr. If we further assume that this minimum sediment accumulation rate is typical for the top 4 m of sediment (the thickness generally affected by minor faults), then the maximum age of the sediment, calculated at 0.8 $cm/10^3$ yr. is 500,000 yrs. B.P. This suggests that the minor faults are no older than Pleistocene in age. If the accumulation rate is much greater, like 10 $cm/10^3$ yrs as is suggested by C^{14} dates from comparable areas farther north (Askren, 1972), then the minor faults could cut sediment as young as 40,000 yrs. B.P.

DISCUSSION AND CONCLUSIONS

Abundant faults cut the St. George basin area. Many faults cut upper Pleistocene sediments and a few reach the surface of the sea floor, indicating that the area is tectonically active.

The southern Beringian continental shelf and margin are located within 500 km of the Aleutian trench, which marks a subduction zone between the Pacific and North American plates. Several intermediate- to deep-focus (71 to 300 km) and many shallow-focus (< 71 km) earthquakes were recorded in the area from 1962 to 1969 (Department of Commerce, 1970). Seismicity in the area during that time interval is shown in Plate 2, Figure D). The shelf of the St. George basin area has been subject to earthquakes with intensities as high as VIII (midified Mercalli scale), which corresponds to a magnitude 5.7 earthquake (Meyer and others, 1976).

Recurrence rates of earthquakes for the area bounded by latitudes 50° and 60°N and lognitudes 160° to 175°W have been as high as 6.4 earthquakes per year from 1963 to 1974 for magnitudes of 4.0 to 8.4, and 0.013 earthquakes per year of magnitude 8.5 to 8.9 (1 every 130 years) from 1988 to 1974 (Meyer and others, 1976).

The correlation of eqrthquakes to shallow faulting is not well understood (see Page, 1975). We believe however, that some faults are active and that they probably respond to earthquake-induced energies and possibly to sediment loading over the St. George basin.

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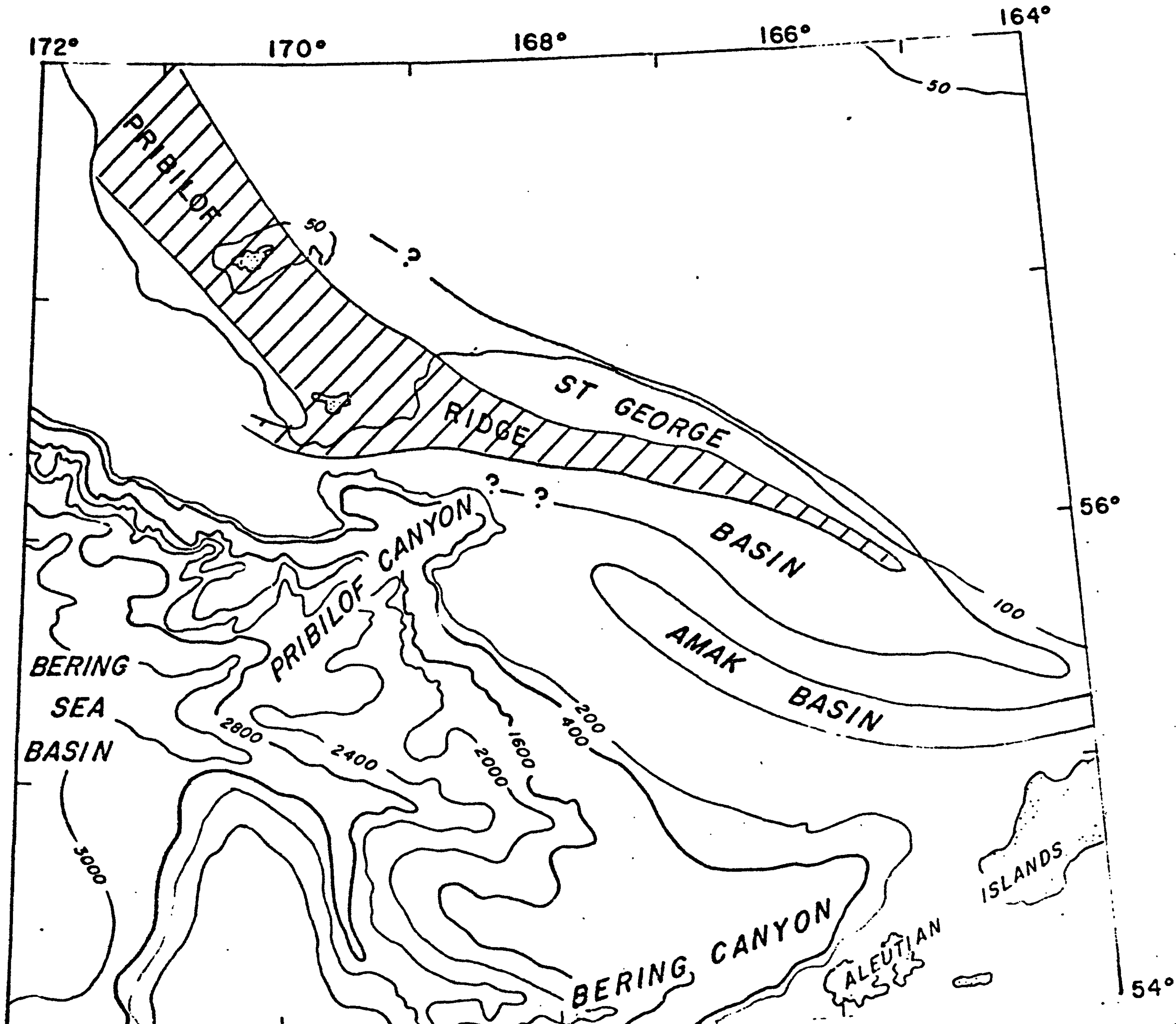

FIGURE 1. The physiography and subsurface features of the Southern Bering Sea. The Pribilof Ridge is shown in diagonal lines, the St. George Basin is outlined but its western extension is not known. Isobaths are in meters.