UNITED STATES DEPARTMENT OF THE INTERIOR
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PRELIMINARY GEOLOGIC INTERPRETATION OF A SEISMIC REFLECTION PROFILE ACROSS THE QUEEN CHARLOTTE ISLAND FAULT SYSTEM OFF DIXON ENTRANCE, CANADA-UNITED STATES

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A joint geophysical study of the continental margin off Graham Island, British Columbia and Dixon Entrance, Canada-U.S., was undertaken in 1977 by the U.S. Geological Survey and the Geological Survey of Canada. Approximately 770 km of 24-channel seismic reflection, single-channel, and high-resolution profiles and magnetic and gravity data were collected aboard the USGS Research Vessel S. P. LEE with Snavely and Tiffin as co-chief scientists.

The purpose of the cruise was to obtain several multichannel seismic reflection profiles across the transform boundary between the Pacific and North American plates where the dextral Queen Charlotte fault defines the seismically active interface (fig. 1). Inferred faults with assumed dextral movement occur 45 km west and 60 km east of the Queen Charlotte fault (fig. 1). These faults are considered to lie within the Queen Charlotte Islands fault system--a major transform regime at least 100 km wide. Studies in progress will integrate the interpretation of multichannel seismic profiles with regional gravity, magnetic, and bathymetric data obtained during cruises of the Geological Surveys of both countries. In advance of this more comprehensive study, a preliminary interpretation of one of our multichannel profiles is herein presented to illustrate the tectonic style and stratigraphic framework along a segment of the continental margin off Dixon Entrance. Work of Chase and Tiffin in 1972 provided significant information on the Queen Charlotte fault in this area and farther south. von Huene and others (1978) in their analysis of the tectonic framework of continental margins of the eastern Gulf of Alaska, included additional data on the structure and stratigraphy off Dixon Entrance. Many of the geologic features they describe, based upon interpretations of single channel seismic reflection profiles, are in agreement with those discussed in this paper. The geophysical review of the continental margin of western Canada by Keen and Hyndman (1979) provides a regional plate tectonic setting that includes the Queen Charlotte fault zone.

The 24-channel profile, A-A' (fig. 2), extends eastward from near the eastern flank of the Kodiak Bowie Seamount chain onto the continental shelf and thence into Dixon Entrance (fig. 1). The profile was obtained using

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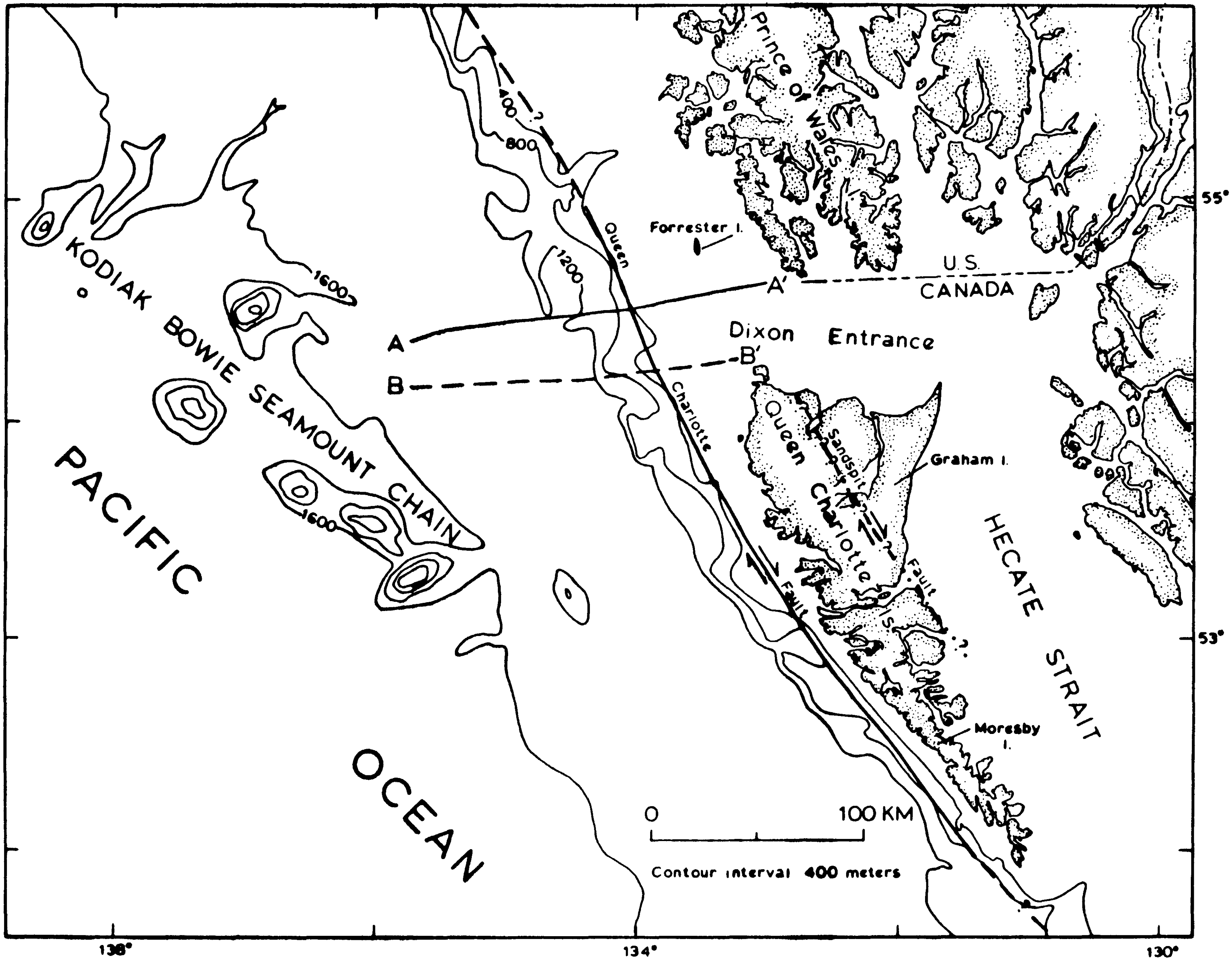

Figure 1.--Index map showing the locations of the 24-channel seismic-reflection profiles A-A' and B-B' and of the Queen Charlotte and Sandspit faults (faults dashed where inferred, queried where projected). Bathymetry after Chase and others (1970).

a sound source of a tuned array of five air guns totaling 1326 in^3. The recording system consisted of a 24-channel streamer, 2400 meters long, and a GUS (Global Universal Science) model 4300 digital recording instrument. The seismic data were sampled at a 2-millisecond rate and later were processed at a 4-millisecond rate. The seismic traces were stacked and filtered but no deconvolution or migration was done. The magnetic data were obtained using a Proton-precession magnetometer; the gravity data were collected using a 3-axis stable-table La Coste-Romberg gravimeter. Navigational control of the survey was by satellite fixes supplemented by doppler-sonar dead reckoning.

GEOLOGIC SETTING

General Statement

The onshore geology adjacent to Dixon Entrance is discussed in several of the reports and maps referred to below; therefore, only a brief summary is presented in this report. Sutherland Brown (1968) described the geology of the Queen Charlotte Islands in a comprehensive report published by the British Columbia Department of Mines and Petroleum Resources. The tectonic history of the adjacent area of southeastern Alaska as reviewed by Brew and others (1966) and the regional geology of southeastern Alaska was compiled by Beikman (1975). A geologic map of the Skeena River area, which covers the part of southeastern Alaska and British Columbia that includes the Queen Charlotte Islands, also provides data on the regional geologic setting (Hutchison and others, 1974). Berg and others (1978) described pre-Cenozoic tectono-stratigraphic terranes of southeastern Alaska and adjacent areas. Their report includes columnar sections that show key stratigraphic units exposed on Prince of Wales Island north of Dixon Entrance and on Graham Island south of the entrance.

Tectonic Framework

Dixon Entrance lies adjacent to the active transform boundary of the Pacific and North American lithospheric plates. The location of this boundary and its sense of movement have been known since the studies by Tobin and Sykes (1968), Sutherland Brown (1968), and Atwater (1970). The present plate boundary is defined by the active dextral Queen Charlotte fault whose movement is estimated at a rate of about 5-6 cm/yr (Minster and others, 1974; Chase and others, 1975; Riddihough, 1977). The interpretation of profile A-A' (fig. 2) suggests that wrench tectonics within the Queen Charlotte Islands fault system probably has dominated both the tectonic and stratigraphic history at least since post-early Miocene time.

The Queen Charlotte Islands are located on the western margin of the continental plate. A well-developed continental shelf is absent along the western side of the islands where the recent trace of the Queen Charlotte fault is located (fig. 1). A steep free-air gravity gradient offshore from Dixon Entrance and the Queen Charlotte Islands marks the change between oceanic and continental crust (Johnson and others, 1971; von Huene and others, 1978).

Stratigraphy

Rocks of Precambrian to Permian age which were assigned to the Alexander terrane by Berg and others (1978), crop out north of Dixon Entrance on Prince of Wales Island. This terrane is characterized by shallow-water carbonate or clastic rocks with associated mafic to silicic volcanic rocks (Berg and others, 1978, columnar section 6). This stratigraphic sequence is markedly different from the Wrangellia terrane of Jones and others (1977) exposed south of Dixon Entrance on the Queen Charlotte Islands, Berg and others, 1978 (columnar section 10).

The suite of rocks on the Queen Charlotte Islands, as described by Sutherland Brown (1968), consists of a thick pile of upper Triassic tholeiitic pillow basalts, a flysch-like sequence of latest Triassic and early Jurassic age, and marine pyroclastic andesite of middle Jurassic age. This older sequence is stratigraphically overlain by less tectonically complex Cretaceous strata and a thick Paleogene sequence of subaerial alkalic basalt flows and sodic rhyolite ash flows. More than 2000 m of Miocene and Pliocene sandstone and siltstone unconformably overlie the older rocks. These Neogene deposits include the Skonum Formation of early late Miocene age (Addicott, 1976) which underlies most of the northeastern part of Graham Island (Sutherland Brown, 1968) and probably occurs in the fault-bounded basins beneath Dixon Entrance (fig. 2).

Inasmuch as the Alexander terrane of southern Prince of Wales Island would project southward across Dixon Entrance into rocks of the Wrangellia terrane exposed on Graham Island, Berg and others (1978) inferred a generally west-trending tectonic boundary in Dixon Entrance between these two unlike terranes. The writers speculate, however, that the northwest-trending Sandspit fault of Sutherland Brown (1968) may separate rocks of the Wrangellia terrane on the west from those of the Alexander terrane on the east where Neogene deposits mask this terrane on the eastern part of Graham Island. If this interpretation is valid, a northwestward extension of the Sandspit fault would cross profile A-A' at a major fault (SP 2870). Farther northwestward the fault would lie west of Forrester Island where Paleozoic rocks of the Alexander terrane crop out (Beikman, 1975). A wedge-shaped slice of Wrangellia terrane may, therefore, be present west of Prince of Wales Island between the Sandspit fault on the east and the Queen Charlotte fault on the west.

Interpretation of Profile

The geologic interpretation of profile A-A' (fig. 2) across the continental margin off Dixon Entrance is discussed in three segments; rise, continental slope and continental shelf.

Rise

In the area of the rise, the depth of water traversed by the profile varies from 2990 m in a deep-sea channel near the western end (SP 360[1/]) to 2500 m at the base of the continental slope (SP 1370). The combination of a shallower sediment-water interface to the east above an eastward-dipping oceanic basement (denoted by the symbol Tmv), produces a wedge of sedimentary rocks that thicken eastward toward the base of the continental slope. Using an average velocity of 3.57 km/sec, obtained from sonobuoy refraction line B-B' (fig. 1) in a similar geologic setting about 25 km to the south, the sedimentary wedge along profile A-A' varies over a distance of about 75 km from 1.8 km thick at the west to 5.6 km thick at the base of the slope. The average eastward dip on the basement reflector, which is interpreted as oceanic crust, is about 4°. This reflector is indicated on the profile by a left-slant short-line pattern.

Sonobuoy velocities within the basement are 6.2 to 6.8 km/sec (uncorrected for dip). Typical of the basement reflector are many strong hyperbolae, possibly indicating a roughness of that surface. In general, the basement surface appears rather featureless except for a small high near the west end of the profile. We consider this deep acoustical basement reflector to be the top of the oceanic layer, as indicated by the seismic velocity and characteristic reflectivity. Within the basement, some faint reflectors lie in the first half-second immediately under the initial basement reflector. This near-horizontal layering appears to be present although it is fragmented by hyperbolae from the basement interface. We suspect that the reflectors beneath the basement surface could be either interbedded pillow basalt and breccia or pillow basalt and interbedded sedimentary rocks. Deeper within the basement, at about 6-seconds at the west end of the profile, a reflector (M) slopes eastward at a steeper dip than the basement surface; the reflector disappears into the multiple near SP 495, at about 7.5 seconds depth. The deep reflector (M) is likely to be the Moho discontinuity which is known from earlier refraction data (Shor, 1962) to be at a depth between about 9.0 and 9.8 km near the line of profile A-A'. Our data give depths of about 8 km on the west and 12 km on the east where it is obscured by the multiple.

Based upon identification of magnetic anomalies (Naugler and Wageman, 1973), the age of the oceanic layer (unit Tmv, fig. 2) is early to middle Miocene and ranges from about 18 m.y. at the west end of the profile to 12 m.y. at the base of the slope.

The sedimentary sequence above the basement is characterized by many continuous, parallel reflectors. The principal acoustic units (A, B, and C) are separated by symbolized lines (X and solid dot). These units are

[1/] The symbol SP refers to the shot point number shown across the top of profile A-A'.

described below from oldest to youngest:

Unit A - This unit is characterized by a series of continuous closely spaced reflectors. The unit dips eastward, subparallel to the basement reflector and thins to the west. The acoustical roughness generated at the basement surface does not extend into unit A except locally in the westernmost part of the profile (SP 390). A correlative acoustical unit overlying the oceanic crust along profile B-B' (fig. 1) has velocities that range from 3700 to 4400 m/sec as determined from sonobuoy data along that profile. Using this velocity, unit A is about 1.4 km thick near the base of the slope. Accepting the age of the basement basaltic rocks as estimated from magnetic anomaly age dating to be as young as middle Miocene, the overlying sediments of acoustical unit A probably range in age from late middle to late Miocene.

Unit B - This unit, which lies conformably on unit A, has reflectors that are continuous over distances of tens of kilometers and are parallel or subparallel to the basal contact. Along profile B-B' sonobuoy data indicate that a correlative of unit B has a velocity of about 3200 m/sec. Along profile A-A' the unit has a constant thickness of about 570 m west of SP 500 but thickens considerably as the slope is approached, reaching a thickness of approximately 2000 m. Unit B shows a number of depositional and erosional features within it or on its paleo-surface. A major submarine channel with its axis between SP 390 and SP 500 existed as a forerunner of the present channel whose axis lies between SP 320 and SP 420. The axis thus shifted westward with time. A broad high in the sediments of this unit centered about SP 750, coexisted with the early channel. Whether the high was a levee, such as has been documented by Normark (1978) on submarine fans off southern California, or a high between two sea channels such as now occur just to the north, cannot be determined with available information. However, the eastward thickening of unit B indicates that a trough was present in the sediments between the high and the continental slope during deposition of unit B.

No direct evidence has been obtained as to the age of these sediments. However, they are inferred to have been deposited in Pliocene time on the basis of sonobuoy data along profile B-B' where a velocity of about 3200 m/sec was obtained for strata in a similar stratigraphic position as B. This velocity agrees closely with that (3400 m/sec) assigned to strata of Pliocene age on the abyssal plain off central Oregon by Snavely and others (1980).

Unit C - Subsequent to the deposition of unit B, sedimentation conditions underwent a change in which (1) the trough at the base of the slope was infilled by sediments which onlapped and overtopped the high to the west, (2) the ancient sea channel (SP 390 to SP 500) was probably filled and almost obliterated by sediments acoustically similar to those that filled the trough to the east. (The axis of the sea channel may have shifted away from the line of profile at this time.) Following the infilling of topographic lows in the sea floor, deposition continued at a greater rate near the continent, resulting in a westward thinning of the unit. The sea channel in the area crossed by profile A-A' was re-established by erosion of sediments of unit C in the vicinity of SP 360.

Unit C is interpreted to be of Quaternary age, although its lowermost part may include some upper Pliocene strata. Velocities for unit C on profile B-B' range between 2000 and 2200 m/sec. Based on these velocities the maximum thickness near the base of the slope is about 1200 m.

Slope

A horst-like ridge, which marks the base of the slope, occurs on the profile between SP 1370 and SP 1415, and is reflected in the bathymetry as one of several en echelon linear ridges resulting from wrench tectonics. The sea floor east of the horst is down-dropped several tens of meters with respect to the sea floor to the west. Although the faults that bound this ridge offset units A, B, and C of the rise sedimentary sequence, these rise units show only minor disruption on a profile 25 km to the south of profile A-A'. Therefore, rise units A, B, and possibly C probably extend east of the ridge under the base of the lower slope to the fault at SP 1540.

East of the horst the gently inclined smooth sea floor surface is interrupted by a graben-like feature that has developed along a fault with apparent down to the west vertical separation (SP 1790 to SP 1805) and the irregularities between SP 1960 and SP 2180. Between east of the horst and the fault at SP 1540, relatively near surface undisturbed strata occur just below the sea floor of the lower slope; however, the deeper layers dip seaward. Near-surface sediments are nearly flat-lying and overlie a low-angle unconformity at about 4.6 seconds that may be equivalent to the base of unit C. An angular truncation occurs at 5.3 seconds.

Hyperbolae and disrupted reflectors in the lower part of the horst make it impossible to deterine if the Miocene oceanic crust below unit A is present beneath the horst. However, on profile B-B' beneath a correlative horst-like structure that involves only units A and B, it appears that an older layered acoustical sequence occurs. This would suggest that the oceanic crust may extend east of the horst on profile A-A', probably as far as the fault at SP 1540.

The sedimentary rocks that underlie the slope east of SP 1540 cannot be directly correlated with the three units beneath the rise as dextral slip may have occurred along what appears to be a major fault at SP 1540. Vertical uplift of older strata along this fault and along the Queen Charlotte fault appear to bound a slope basin. Most of the strata in this basin (above the line marked with open triangles) may be correlative in age with the rise sequence.

Between the fault at SP 1540 and the Queen Charlotte fault, a sequence of deformed strata unconformably underlies the slope basin sediments. The older strata appear to be a folded and faulted sedimentary sequence of inferred early and middle Tertiary age.

Between SP 1668 and SP 1780, sediments are well layered and dip eastward off the axis of a faulted anticline. The west limb of the fold is cut by faults between SP 1640 and SP 1660. An onlap unconformity between the slope-basin strata and the older sequence is well shown on the east limb of the fold. Acoustic reflections above the unconformity produce a high-frequency signal, possibly indicating thin-bedded sedimentary rocks. Faults between SP 1780 and SP 1810 bound a small depression or graben at the sea floor across which the angle of the continental slope increases somewhat on the seaward side. These faults appear to separate east-dipping reflectors to the west from west-dipping reflectors to the east.

The small truncated anticline beneath the sea floor at SP 1685 may be related to the northwest-trending ridge whose bathymetric relief terminates a short distance south of the profile. Based upon the interpretation of profile A-A' and others to the south, the linear ridges on the slope are fault-bounded blocks that developed along faults within this right-lateral strike-slip regime.

From SP 1800 to the base of the steep upper part of the slope, offset reflectors indicate that faults are present in the slope-basin strata of probable Pliocene and Miocene age, but none of these faults cuts the youngest (Quaternary) sedimentary layers above the unconformity indicated by the open-square symbol. The surface irregularity in the upper part of the slope, between SP 1950 and SP 2175, suggests downslope mass movement of the youngest sediments. Along this 20 km section of the profile continuous reflectors of the slope-basin strata below the Quaternary unconformity are gently folded, generally westward dipping and onlap older rocks. This sedimentary rock sequence unconformably overlies an older faulted and folded sedimentary sequence which rises to within a few tens of meters of the sea floor on the steep part of the upper slope. These older strata, between SP 2070 and SP 2165, dip more steeply to the west than the overlying sediments and can be followed westward beneath the unconformity denoted by open triangles.

The uppermost slope, between SP 2250 and SP 2325, is cut by faults of latest Pleistocene(?) and Holocene age in the active part of the Queen Charlotte fault zone. The small trench at SP 2300 may represent a section across a linear trough or graben along the recent trace of the fault.

Shelf

The surface of the continental shelf traversed by profile A-A' along the northern part of Dixon Entrance is broad and nearly horizontal east of SP 2330. In contrast, the shelf off the Queen Charlotte Islands to the south is either very narrow or absent. The generally smooth surface of the shelf is mantled by a veneer of Pleistocene(?) and Holocene deposits, but a few basement highs (beneath the right-slant short-line symbol) disrupt its planar surface. The sea floor slopes gently eastward from the shelf break and water depths average about 300 m along the profile.

Although numerous multiples in the shelf segment of the seismic profile make it difficult to interpret the geology, the general structural framework can be discerned. The shelf is characterized by fault-bounded pre-Tertiary(?) "basement" highs[1/] that separate narrow, asymmetric sedimentary basins. Strata of presumed late Miocene to Pleistocene age in these basins thicken gradually westward off the basement structural highs but are more steeply dipping and are faulted against basement rocks along the western margins of the basins. The deepest of the basins is bounded on the west by a fault at SP 2870 and on the east by an uplifted basement block which forms Learmonth Bank near SP 3300. More than 4000 m of strata may occur in the deepest part of this basin but the sequence thins rapidly eastward as it onlaps the Learmonth Bank basement high. The structural basins on the shelf are similar to those formed in the wrench-fault realm of the southern California borderland described recently by Howell and others (1980, fig. 8). The westward-tilted blocks of strata in shelf basins on profile A-A' generally lack compressive folds, suggesting that crustal extension resulting from wrench faulting occurred east of the Queen Charlotte fault zone. Interpretation of a high-resolution (Uniboom) profile indicates that several of the faults on the shelf offset the sea floor and, in several places, as near SP 3000, the pre-Tertiary basement rises above the sea floor.

Summary

The preliminary interpretation of the structural and stratigraphic framework along profile A-A' indicates that faults reflecting wrench tectonics occur both east and west of the Queen Charlotte fault zone. This system appears to extend 45 km west of the Queen Charlotte fault to the base of the slope and about 60 km east of the fault to near the east end of the profile, a distance of more than 100 km. Structures within this fault system indicate that lateral displacement along the transform boundary between the Pacific and North American plates has produced both tensional and compressional features. Warping and offset of the sea floor indicates that the

[1/] The rock units beneath the basement contact (unit pre-T(?)) contain a few discernable acoustical reflectors and may represent either Mesozoic strata or interbedded basalt flows and ash-flow tuffs of the early or middle Tertiary Masset Formation (Sutherland Brown, 1968).

deformation is continuing today. The seismic activity within the Queen Charlotte Islands fault zone (Tobin and Sykes, 1968; Milne and others, 1978; Keen and Hyndman, 1979) suggests that recent movement may have occurred along several faults within the zone. However, the Queen Charlotte fault zone on the upper slope appears now to dominate the displacement along the Pacific-North American transform boundary.

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Figure 2. Preliminary geologic interpretation of 24-channel seismic reflection profile off Dixon Entrance, United States-Canada

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