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GLORIA INVESTIGATION OF THE EXCLUSIVE ECONOMIC ZONE IN THE GULF OF ALASKA AND OFF SOUTHEAST ALASKA: M/V FARNELLA CRUISE F7-89-GA, JUNE 14-JULY 13, 1989

by

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INTRODUCTION

Cruise F7-89-EG (Figures 1 and 2) of the M/V Farnella was the fourth survey in a four cruise multi-year program designed to image the Gulf of Alaska Exclusive Economic Zone (EEZ) using GLORIA (Geological Long Range Inclined Asdic), a long-range side-looking sonar system (Somers and others, 1978; Swinbanks, 1986). The Gulf of Alaska study is part of a cooperative research program between the United States Geological Survey (USGS) and the British Institute of Oceanographic Sciences (IOS) in Wormley, England. The objective of this program is to produce an atlas that shows the geologic and morphologic features of the seafloor so as to better evaluate the economic potential, geologic hazards, and other possible uses of the Alaskan EEZ.

The GLORIA surveys are conducted from the M/V Farnella, which is under lease to the USGS through IOS. In addition to collecting GLORIA data, science operations include acquisition of two-channel seismic-reflection profiles using an air gun signal source, 3.5 kHz high-resolution profiling, 10kHz echo-sounding bathymetry, and magnetic and gravity potential-field measurements.

Prior to cruise F7-89-EG, other cruises insonified the rest of the EEZ in the Gulf of Alaska. Cruise F1-86-GA imaged a 400 km segment of the continental slope centered around Middleton Island in the northern Gulf of Alaska in 1986 (Figure 1). Cruise F8-88-AA covered part of the region between Unimak Pass and the Shumagin Islands (Vallier and others, 1989). Cruise F9-88-WG imaged the western Gulf of Alaska EEZ off the Alaska Peninsula between Unimak Pass and the center of Kodiak Island in 1988. The central Gulf of Alaska was surveyed in 1989 on cruise F6-89-GA (Carlson and others, 1990b), which covered the region between Kodiak Island and Yakutat Bay

During cruise F7-89-EG, GLORIA images were collected along northwest-southeast tracklines oriented parallel to the continental margin for about 140 km seaward of the margin; the remainder of the coverage is on tracklines oriented northeast-southwest (Figures 1 and 2). At Cross Sound and Dixon Entrance, special lines perpendicular to the margin were also obtained to provide a different perspective for the GLORIA images. A pair of GLORIA lines were run along the Queen Charlotte Islands off British Columbia to follow the southward extension of the Queen Charlotte-Fairweather fault system to the Tuzo Wilson Knolls. Lines in Canadian territory also image the southeastern extension of the Kodiak-Bowie seamount chain, and the southward extension of major turbidite channels that originate off southeast Alaska.

Data collected during the cruise include about 9795 line km of GLORIA, seismic reflection, bathymetric, and magnetic, and gravity data. About 260,000 square km of ocean floor were insonified using the GLORIA system, of which about 62,000 square km lie south of the U.S./Canada border extended offshore from Dixon Entrance.

SCIENTIFIC PARTICIPANTS

Scientific participants and senior ship's officers staffing the M/V Farnella for cruise F7-89-EG were as follows (BGS - British Geological Survey; JMarr - Ship Operations Company; RVS, British Research Vessel Services; Univ. Wales - Institute of Earth Studies, University College of Wales, Aberystwyth, Wales; USGS - U.S. Geological Survey):

Terry R. Bruns (USGS)	Co-Chief Scientist
Andrew J. Stevenson (USGS)	Co-Chief Scientist
Maxwell R. Dobson (Univ. Wales)	Co-Chief Scientist
Jon Campbell (IOS)	Electrical Engineer
Steve McPhail (IOS)	Electrical Engineer
Michael Boyle (USGS)	Electronics Technician
Steve Whittle (IOS)	Marine Technician
LedaBeth Pickthorn (USGS)	Navigator
Grace Fong (USGS)	Navigator, Data Curator
Gareth Knight (RVS)	Navigator
Jeremy Evans (IOS)	Photographer
Heidi Dieffenbach (USGS)	Geologist
John Cannan (JMarr)	Ship Captain
Bill Wilson (JMarr)	Chief Mate
Mike Baldwin (JMarr)	Chief Engineer

EQUIPMENT SYSTEMS

GLORIA side-scan sonar system

The GLORIA system is towed at a depth of 40 to 50 m, 400 m behind the vessel, at speeds of 8 to 10 knots. For protection of the GLORIA fish, the system is virtually always used in water depths greater than 300 m, thus limiting data acquisition largely to continental slope and deeper regions, but with some information returned from seafloor irregularities near the edge of the shelf. The sonar array in the GLORIA fish consists of two rows of 30 transducers each, on either side of the fish. These transducers send a burst of energy at 30 s intervals at frequencies of 6.3 kHz and 6.7 kHz and with a 100-Hz bandwidth. Incoming signals from the port and starboard sides are recorded separately, the data are corrected for distortions due to slant-ranging and changes in ship's speed, and shipboard photographic images are produced. Data are recorded in digital format, and computers are used post-cruise to reprocess and enhance the GLORIA images. The GLORIA system functioned without major problems throughout the entire cruise

Navigation

Navigation was controlled by GPS satellite and Loran-C, with transit satellites occasionally used when necessary. GPS coverage was about 14 hours per day. Onboard processing used GPS satellites and Loran-C positions to generate 2 minute navigation fixes. Processing also allowed for a comparison of each of the three navigation systems, and integration of the best system into the final trackline navigation map.

Seismic-reflection profiling

The two-channel seismic profiling system utilized a 160 cubic inch airgun, a 10 s fire rate, and a 6 s sweep rate. Returning signals were received by two 50 m long active sections towed about 500 to 600 m behind the ship. The data were recorded in analog form on a Raytheon LSR and digitally in SEGY format on 1600 bpi tapes on a MASSCOMP seismic recording system. Recording cable and electronic equipment problems were minimal throughout the cruise, and the only significant loss of data occurred during storm periods when wave action caused noise on the recording cable. Normal airgun maintenance was carried out either during line changes or on short connecting transit line. Problems were minor, and included compressor malfunctions, leaking air-hose packages, and various airgun malfunctions; these problems were repaired with minimal lost data. All lines will be digitally processed by the USGS for interpretation and final presentation.

High resolution seismic systems - 3.5 kHz and 10 kHz

Two high-resolution seismic-reflection systems using towed vehicles were run throughout the cruise. The 3.5 kHz system was run with a 1 s sweep rate, while the 10 kHz system was run with a 2 s sweep rate. Bathymetric depths were read off the 10 kHz system every 6 minutes and input into the processing system for slant range correction of the GLORIA data. Neither system experienced major problems during the cruise

Gravity and Magnetic Data

Gravity data was acquired with a LaCoste and Romberg meter (S-53) and recorded on strip charts and digital tape. Gravity ties to land-based gravity stations were made at Yakutat, Alaska and Redwood City, California at the beginning and end of the cruise.

Magnetic data were recorded with a Geometrics magnetometer which functioned continuously throughout the cruise. Data were recorded on strip charts and on digital tape with the gravity data.

Gravity and magnetic data were processed and plotted out during the cruise at a scale of 1:375,000 to match the onboard GLORIA mosaic, and at a variable scale (measured) to match Polaroid pictures of the seismic-reflection data. The ability to play out the potential field data allowed for onboard comparisons of features from the GLORIA and seismic-reflection systems with the gravity and magnetic data.

Expendable bathythermograph - XBT

Expendable bathythermographs were deployed once per day at about noon, local time to monitor the thickness of the mixed water layer and the water temperature. The resulting data were broadcast to NOAA by satellite on a daily basis.

CRUISE COMMENTS

Cruise F7-89-EG departed Yakutat Alaska at 0948, June 14, 1989. All gear was deployed beginning at about 2200, June 14, with GLORIA data collection commencing at 0041, June 15. A major interruption to data collection occurred only once during the cruise, from 1313-2100, June 22, to replace the GLORIA cable. Otherwise, scientific gear functioned with only minor down-time for breakdowns or normal maintenance. The weather was not a significant factor in either the data collection process or data quality, with only a few periods of high winds (from 30-45 knots) and rough seas occurring between June 14 and June 26. From June 26 on, winds were light and seas were calm for the remainder of the cruise. Data collection ended at about 0120 on July 10, all gear was retrieved, and the transit to Redwood City began. The cruise ended at 1130, July 13, 1989 at Redwood City, California.

REGIONAL GEOLOGIC SETTING

The mostly submerged Queen Charlotte-Fairweather fault system lies along the southeast Alaska and British Columbia continental margins, and is the active transform boundary between the Pacific and North American plates. The fault system begins at the Tuzo Wilson Knolls (Figure 1), at the end of the complex intersection of the Juan de Fuca spreading ridge and the North American continental margin off southern British Columbia. The fault system trends northward along the British Columbia and southeast Alaska continental margins as the Queen Charlotte fault to Icy Point in the northern Gulf of Alaska. At Icy Point, the offshore fault system merges with the onshore Fairweather fault of southern Alaska. Movement along the transform system is about 6 cm/yr (Minster and Jordan, 1978; DeMets and others, 1990). The fault system has a total length similar to the better-exposed and better-studied San Andreas fault of California.

The adjacent ocean plate is virtually zero age at the Tuzo Wilson Knolls, and of Miocene and older age off southeast Alaska based on magnetic anomalies (Naugler and Wageman, 1973; Stevenson and Embley, 1987) The ocean plate is covered by a complex system of turbidite fans, including the Surveyor, Horizon, and Mukluk systems (Stevenson and Embley, 1987), and the Chirikof system, delineated by the new GLORIA data, that have their origins off southern and southeastern Alaska. The turbidite channels wind through the Kodiak-Bowie seamount chain, and variously end at the Aleutian Trench (Surveyor Channel), on the south side of the Kodiak-Bowie seamount chain (Chirikof Channel system), or stretch over 1000 km southwards to end in the Tufts Abyssal Plain (Horizon and Mukluk channels).

Marine geophysical data collected off southeast Alaska have been used to study the offshore fault and fan systems. von Huene, Shor, and Wageman (1979) used widely spaced single-channel seismic-reflection profiles to identify faults and submarine scarps on the shelf south of Icy Point which appeared to align with the onshore trace of the Fairweather fault. However, their seismic profiles were too widely spaced to allow detailed mapping of offshore faults. Carlson and others (1979) and Carlson, Plafker, and Bruns (1985) used more closely spaced (2-10 km spacing) single-channel seismic-reflection profiles collected in 1978 to map the offshore fault between Cross Sound and Chatham Strait. However, only widely spaced (25-50 km spacing) multichannel seismic-reflection profiles were available for the region south of Chatham Strait (von

Huene, Shor, and Wageman, 1979; Bruns and others, 1984; Bruns and Carlson, 1987). And only scattered lines were available to study the abyssal plain fan systems (Stevenson and Embley, 1987), and these lines were in general insufficient to map the details of the fan channels, or to determine the interrelationships between the fans.

PRELIMINARY CRUISE RESULTS

THE 1989 GLORIA data reveal in striking detail the presently active traces of the submerged part of the Queen Charlotte-Fairweather fault system and the extent and configuration of the turbidite fan systems.

Queen Charlotte-Fairweather fault system

From Cross Sound to south of the Queen Charlotte Islands, the active trace of the Queen Charlotte fault is strikingly imaged as a narrow linear feature composed of ridges and troughs that have vertical offset. Seafloor changes are sufficient that the linear trace or traces of the fault can be followed on the GLORIA data even on the outer shelf. The location of faults on the shelf based on the GLORIA data is in good agreement with the faults mapped on high-resolution seismic reflection data by Carlson, Bruns, and Plafker (1985).

From Cross Sound to Chatham Strait, the fault system is on the shelf and is comprised of two sets of subparallel fault traces separated by 3 to 6 km (Figure 3). The fault system crosses the shelf from Icy Point to south of Yakobi Valley, then follows the shelf edge to Chatham Strait. Between Chatham Strait and Dixon Entrance, a single, sharply-defined active fault trace underlies the upper and middle slope. This fault segment is in part bounded on the seaward side by a high, mid-slope ridge (Figure 4). Southeast of Dixon Entrance, the active fault trace trends back onto the outer shelf or upper slope until midway along the Queen Charlotte Islands, then cuts back to and stays at mid-slope to the Tuzo Wilson Knolls south of the Queen Charlotte Islands. The Queen Charlotte fault's active trace steps westward at the Tuzo Wilson Knolls; the knolls are either part of a small spreading segment, or are caused by volcanism associated with a pull-apart structure developed between the parallel strike-slip faults (leaky transform). The southern part of the fault system, from about 53^{o} southward, has also been previously imaged with high-resolution SEABEAM acoustic images (Davis, Currie, and Sawyer, 1987).

Horizontal offset along the fault is visible in an offset canyon wall of Yakobi Trough, in an offset submarine canyon between Dixon Entrance and Chatham Strait, on offset channels off Dixon Entrance, and on offset turbidite channels off both Dixon Entrance and Chatham

Strait (described later). The canyon wall of Yakobi Trough shows right-lateral displacement of 300 to 700 m of the 200 m bathymetric isobath. This displacement accumulated as a result of Holocene displacement along the fault zone since retreat of the glacier that carved the valley (von Huene, Shor, and Wageman, 1977; Carlson and others, 1979; Atwood and others, 1981; Carlson, Plafker, and Bruns, 1985; and Bruns and Carlson, 1987). A turbidite channel north of Dixon Entrance (Figure 4) is incised through a high ridge and is offset northward along the fault about 25 to 30 km, which would require about 0.5 my at current offset rates. Finally, numerous small drainage channels that cross the active fault trace off Dixon Entrance are deflected northward as they cross the fault (Figure 4).

Numerous synclines and thrust-faulted anticlines are present seaward of the Queen Charlotte fault (Figures 3 and 4). Large structures (up to 35 km wide; as much as 50 km long) along the lower slope west and north of Dixon Entrance may be wrench-fault structures similar to those seen along the onshore San Andreas fault, although these structures trend parallel to the fault, rather than forming an en-echelon pattern that is commonly seen along strike-slip faults. A high, narrow (less than about 5 km wide) linear mid-slope structure off Dixon Entrance (outlined in Figure 4) is probably a shutter ridge--a ridge displaced northward along the fault and now blocking drainages off the shelf. The fault trace lies at the base of the east side of this ridge, and the maximum displacement, about 30 km, of any channel or drainage system along the fault is on a major channel that cuts through the ridge.

Alaska abyssal plain

Cruise F7-89-EG imaged parts of four turbidite systems that cross the Alaska abyssal plain, the Surveyor, Chirikof, Horizon, and Mukluk turbidite systems (Figure 2).

The Surveyor channel system is comprised of tributary channels that arise along a 220 km long stretch of the continental margin between the Bering Trough and Alsek Valley. These channels eventually coalesce on the abyssal plain about 200 km south of the margin into a single channel, Surveyor channel. Cruise F7-89-EG imaged only the upper slope and western-most lower slope drainages of the Surveyor channel system; the system is mainly described by Carlson and others (1990 a, b; in press). Surveyor channel trends southwest past Giacomini seamount, then turns northwest and plunges into the Aleutian Trench southeast of Kodiak Island. Sediment delivered by the Surveyor channel system or by slope canyon systems into the Aleutian Trench is subsequently transported southwestward along the Aleutian Trench.

The Chirikof channel system (Figure 2) arises in feeder drainages originating from the 230 km long continental margin segment between Alsek Valley and Mt. Edgecumb (near Sitka), with the greatest sediment input coming from Cross Sound. As with the Surveyor channel system, these drainages coalesce about 200 km from the base of the slope to form a single channel. The resulting channel trends southwest to the Kodiak-Bowie seamount chain, turns west along the chain, winds south through the chain between Quinn and Surveyor seamounts, and finally terminates in a turbidite fan complex south of Surveyor seamount. Cruise F7-89-GA mainly imaged the portion of this system north of the Kodiak-Bowie seamount chain (Figure 2).

Portions of an abandoned channel, now buried by overbank deposits of both the modern Surveyor and Chirikof channel systems are present just north of Chirikof channel near the seamount chain, and just south of Surveyor channel on the long northwest plunge into the Aleutian trench. This abandoned channel probably drained the margin from Yakutat Seavalley to Fairweather Ground, although the exact drainage region is obscured by the younger proximal regions of the Surveyor and Chirikof systems. The Surveyor and Chirikof systems appear to have originally developed in topographically low interchannel regions on either side of the abandoned channel.

The ages of the Surveyor, Chirikof, and abandoned channel systems are known only from samples from DSDP Hole 178 near Giacomini seamount. At this site, the Surveyor fan is dated as late Miocene and younger (Stevenson and Embley, 1987). Within the fan two distinct seismic sequences are present. The lower sequence is about late Miocene to earliest Pliocene, and is probably derived from a fluvial source; this sequence may consist of sediments deposited from the older channel system. The upper sequence (Surveyor sequence) is early Pliocene and younger, is derived from the modern Surveyor fan, and contains glacially derived sediment. Interfingering of fan overbank deposits of the Surveyor and Chirikof systems then indicates that both systems are at least Pliocene and younger, and could be late Miocene and younger.

No clearly offset channels are observed along the continental margin between Cross Sound and the Bering Trough (Yakutat margin), and no evidence for compressional deformation or strike-slip faulting is observed on the GLORIA records. The heads of the fans do not appear to be truncated. Thus, the fans appear to have been derived from the Yakutat margin throughout their history with no strike-slip offset along the margin or subduction of Pacific plate beneath the margin. If so, the Yakutat margin and the Pacific plate have remained in proximity to each other since the late Miocene.

The Horizon channel system begins off Chatham Strait (Figures 2 and 3). Sediment input to the fan comes largely from the region of Chatham Strait, as the southeastern Alaska islands and the intervening glacier-cut waterways channel any glaciers or outlet currents towards the Chatham Strait area. The channel system's upper slope drainage channels originate from a 125 km long margin segment, a much narrower region than the gathering areas for the Surveyor and Chirikof systems. The presently active Horizon channel system begins with 3 major drainages; two of these drainages encircle a prominent submarine lower slope fan (outlined in Figure 3). The channel arms coalesce into Horizon channel, which trends southwest, crosses the Kodiak Bowie seamount chain southeast of Brown seamount, than turns almost 90^{o} counterclockwise to parallel the chain and runs southeast to the edge of the GLORIA coverage. The channel then extends over 1,000 km southward to the Tufts Abyssal Plain (Stevenson and Embley, 1979).

At least two abandoned or only partly active channels are present northwest of the active Horizon Channel system (Figure 2). One of these abandoned channels forms a spectacular series of sweeping meanders for about 100 km seaward of the base of the slope. Fan deposits show that the northernmost abandoned channel is oldest, as overbank deposits from the meandering channel bury the sediments deposited from the northern channel. Similarly, sediments from the presently active Horizon system overlie the deposits from the meandering system. The abandoned systems, and the active northern arm at the base of the slope all appear to reflect northward offset from Chatham strait along the Queen Charlotte-Fairweather fault system. Offset of the northernmost abandoned channel is about 125 km, which would require about 2 my of motion along the fault at the current rate of about 6 cm/yr.

The Mukluk Channel system begins off Dixon Entrance (Figures 2 and 4). As with the Horizon channel system, sediment input into the fan system is gathered from about a 125 km long region of the shelf, as the islands and fjords of southeast Alaska channel the glaciers and drainage systems into the Dixon Entrance area. The Mukluk system has three major arms, with the northernmost arm beginning east of and cutting through the high shutter ridge at midslope. The three arms coalesce into Mukluk channel about 50 km from the base of the slope. The Mukluk channel then cuts through the Kodiak-Bowie seamount chain by winding in a circuitous path north of Dickins seamount, meandering eastward around Denison, and crossing between Denison and Davidson seamounts. As with Horizon channel, Mukluk channel then trends southeast to the edge of the GLORIA coverage, and eventually extends over 1,000 km southward to the Tufts Abyssal Plain (Stevenson and Embley, 1979).

The northward arm of Mukluk channel is offset a maximum of about 125 km north of Dixon Entrance, which, as with the Horizon channel system, would take about 2 my at the current offset rate along the Queen Charlotte-Fairweather fault system.

SUMMARY

The GLORIA data acquired on cruise F7-89-GA add significant new information to knowledge of tectonic and depositional systems of the Gulf of Alaska. From Cross Sound to south of the Queen Charlotte Islands, the active trace of the Queen Charlotte fault is strikingly imaged as a narrow linear feature composed of ridges and troughs that have vertical offset. Horizontal offset is visible on offset drainages and channels. Numerous large structures are present seaward of, and trend parallel to the fault. The active fault trace steps westward at the Tuzo Wilson Knolls, which structurally may be either pull-apart volcanic ridges or part of a small spreading ridge segment.

On the abyssal plain, turbidite channels form four separate drainage systems. The Surveyor channel system is comprised of tributary channels which arise along the margin between the Bering Trough and the Alsek Canyon, and coalesce on the abyssal plain into a single channel, Surveyor channel, that ends at the Aleutian Trench southeast of Kodiak Island. The Chirikof channel system arises from the margin between Alsek Canyon and Sitka, eventually forming a single channel that terminates in turbidite fans south of the Kodiak-Bowie seamount chain. The Horizon channel system starts along southeast Alaska off Chatham Strait, and the Mukluk system off Dixon Entrance. Both systems wind through the Kodiak-Bowie seamount chain, and end more than 1,000 km to the south on the Tufts abyssal plain. The abandoned and active fans and channels of the Horizon and Mukluk systems show a southward age progression from older to younger, and record deposition from a narrow region of the margin off, respectively Chatham Strait and Dixon Entrance, with subsequent Quaternary offset northward along the Queen Charlotte-Fairweather fault system.

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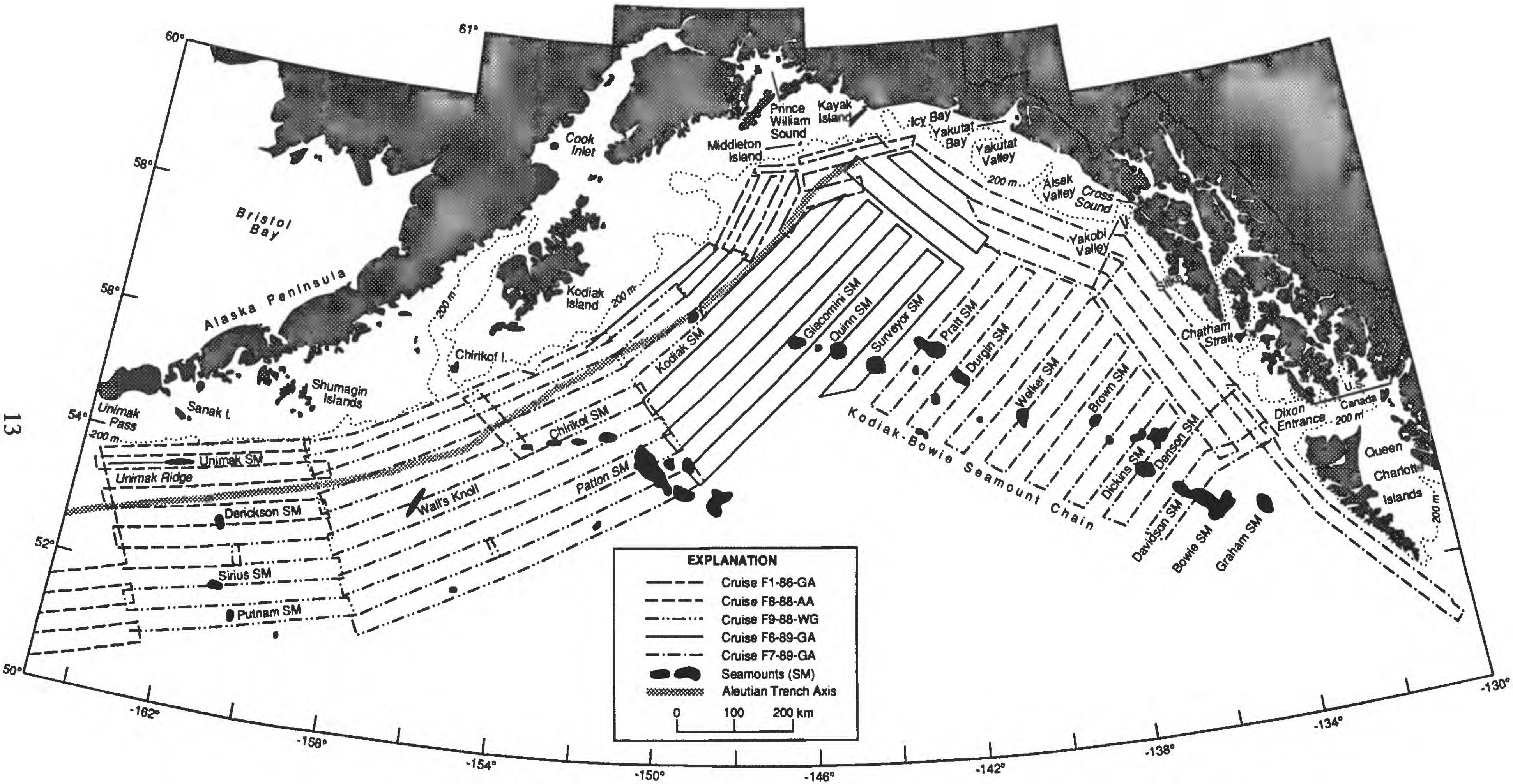

Figure 1. Index map showing GLORIA tracklines in the Gulf of Alaska. Dotted line shows 200 m bathymetric contour.

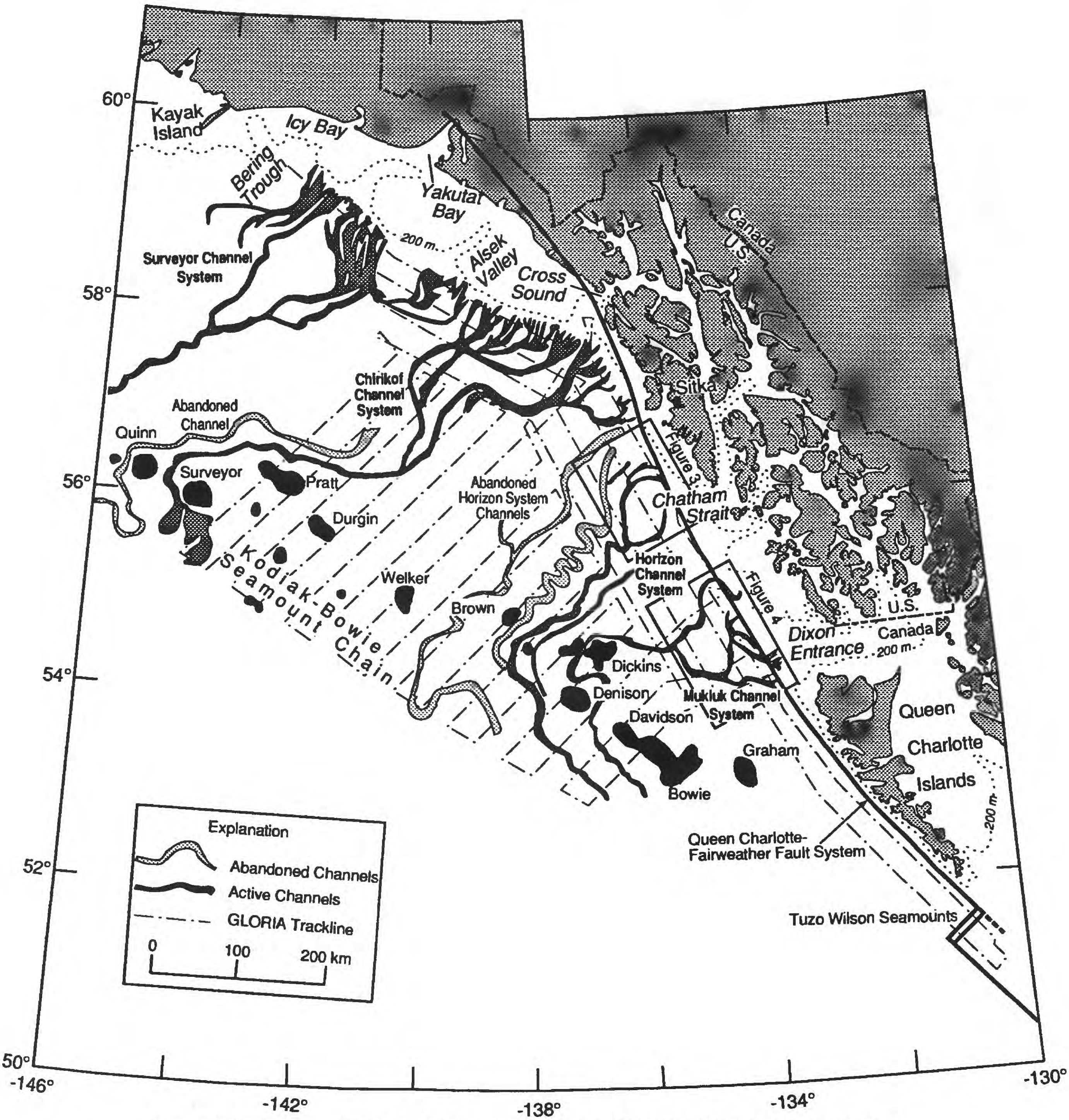

Figure 2. Index map of the southeast Alaska - Queen Charlotte Islands region showing tracklines for cruise F7-89-GA, the general location of the Queen Charlotte-Fairweather fault system, and turbidite channel systems mapped on GLORIA data. Two boxes off Chatham Strait and Dixon Entrance outline areas shown in Figures 3 and 4. Dotted line shows 200 m bathymetric contour.

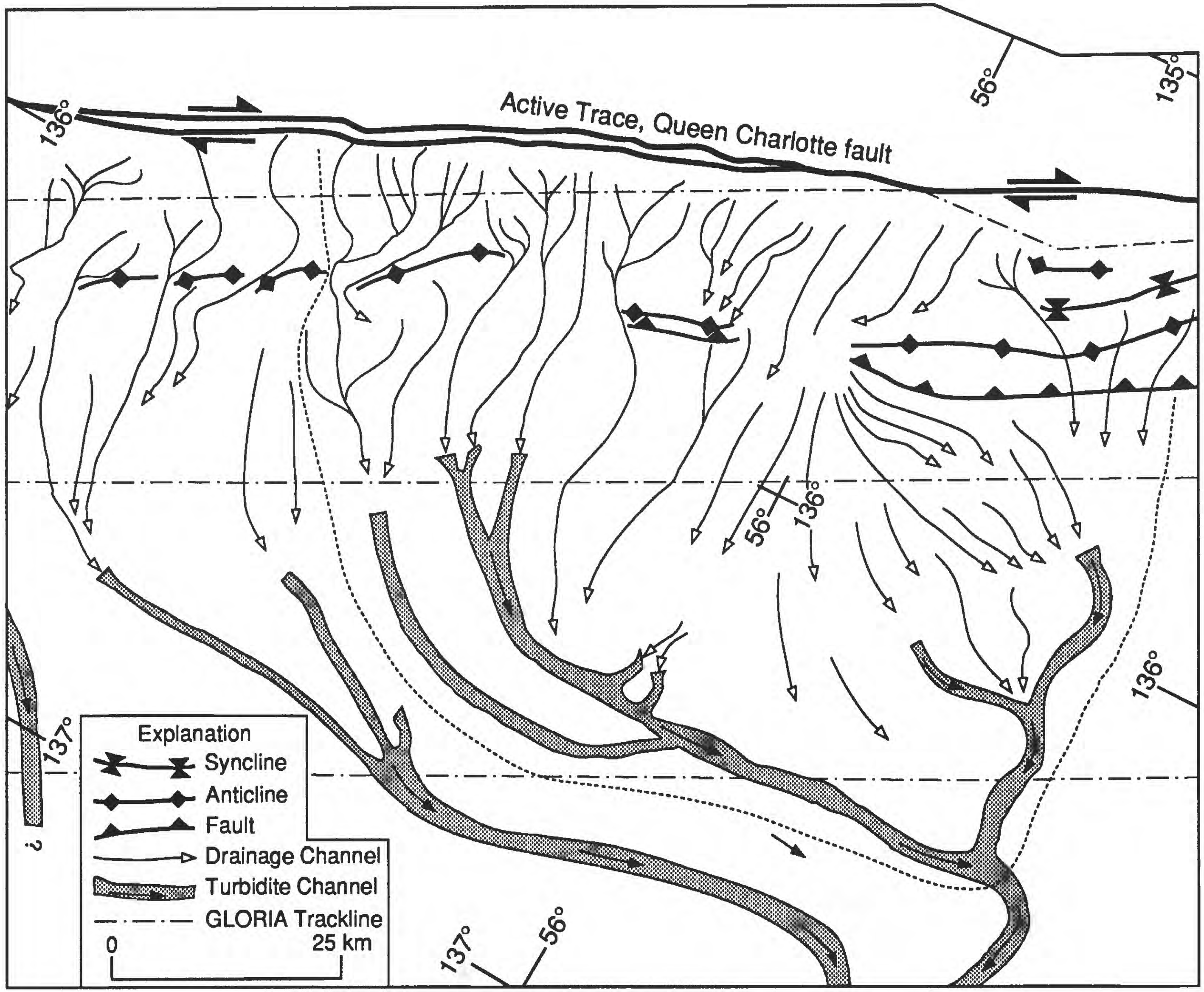

Figure 3. Interpretive sketch map from the GLORIA and seismic reflection data of structures, drainage pathways, and the upper reaches of the Horizon Channel system off Chatham Strait; the location of the figure is shown in Figure 2. The turbidite channels meet just west of the figure to form the modern active Horizon channel. Dotted line outlines region of a lower slope, cone-shaped fan.

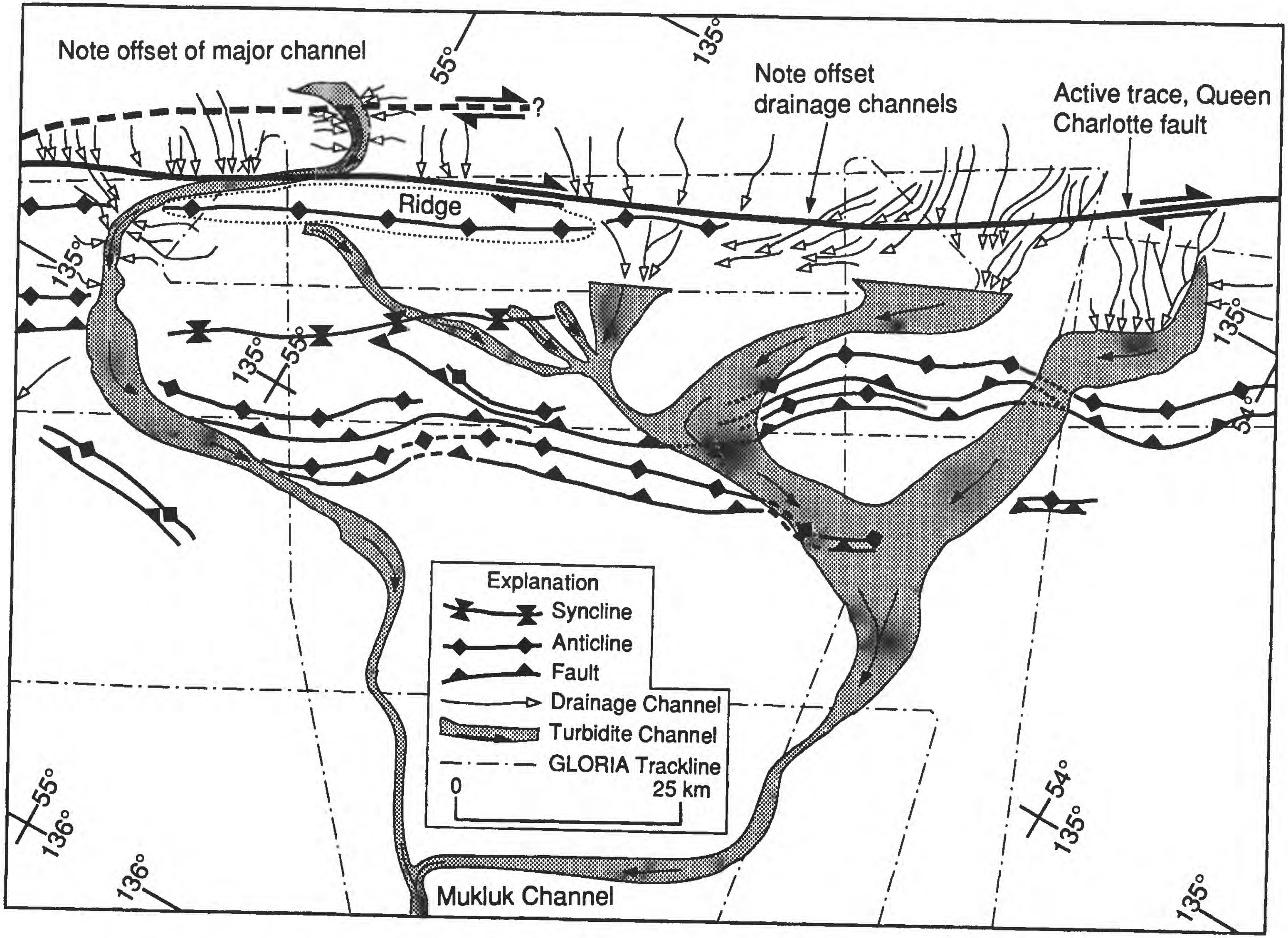

Figure 4. Interpretive sketch map from the GLORIA and seismic reflection data of structures, drainage pathways, and the upper reaches of the Mukluk channel system off Dixon Entrance; the location of the figure is shown in Figure 2. Dotted line near north end of figure outlines a high, narrow ridge that is probably a shutter ridge formed of material displaced northward along the fault system.