GRAVITY MAP SERIES

of the

DOMINION OBSERVATORY

Ottawa

Gravity Measurements in British Columbia with map No. 88 - British Columbia coastal area

R. A. Stacey, L. E. Stephens,
R. V. Cooper and B. G. Brulé

OTTAWA, CANADA

Department of Energy, Mines and Resources
OBSERVATORIES BRANCH
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CONTENTS

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ABSTRACT - Gravity Map No. 88 covers the coast area of British Columbia and includes the continental shelf, Vancouver Island, the Queen Charlotte Islands and the fiords of the mainland. The Bouguer anomalies have been contoured at 10 mgal intervals and are based on gravity measurements every 12 to 15 km. The terrain corrections have been computed using either a rectangular or a circular graticule or a combination of both depending on the scale of the available topographic maps.

The major features of the gravity field are: a positive Bouguer anomaly along the western edge of the area, which is associated with the change from continental to oceanic crust, and a negative anomaly along the Coast Mountains which is attributed to the thickening of the continental crust below these mountains. Over the eastern part of the Queen Charlotte Islands, Hecate Strait, Queen Charlotte Sound and Vancouver Island, changes in the Bouguer anomaly values have been related to density variations in the surface rocks.

RÉSUMÉ - La carte gravimétrique n° 88 couvre la région côtière de la Colombie-Britannique, y compris le plateau continental adjacent, l'île Vancouver, les îles Reine-Charlotte et les fjords continentaux. Le tracé des anomalies de Bouguer dont les isogammes sont espacées de 10 mgals s'appuie sur un réseau de mesures distantes de 12 à 15 km. On a calculé les corrections de terrain à l'aide d'un graticule rectangulaire ou circulaire, ou encore d'une combinaison des deux à l'échelle des cartes topographiques disponibles.

Les principales caractéristiques du champ gravimétrique sont: une anomalie de Bouguer positive le long du bord ouest de la région, correspondant au passage de la croûte continentale à la croûte océanique, et une anomalie négative le long de la chaîne Côtière laquelle serait due à l'épaississement de la croûte au droit des montagnes. Les valeurs variables de l'anomalie de Bouguer, au niveau de la partie est des îles Reine-Charlotte, du détroit d'Hécate, du détroit de la Reine-Charlotte et de l'île Vancouver, sont attribuées aux variations de densité des roches de surface.

INTRODUCTION

Gravity Map No. 88, which accompanies this report, includes the results of several years work by members of the Gravity Division of the Dominion Observatory on the coast of British Columbia. The map shows the Bouguer anomaly field over the continental shelf between latitude 48°N and the Alaska border at latitude 54°40'N and includes Vancouver Island, the Queen Charlotte Islands, the lowland areas of the mainland and the majority of the fiords which extend well into the Coast Mountains (Figure 1). Apart from the Bouguer anomaly values over the southern part of Vancouver Island and the adjacent mainland which have been taken from Walcott (1967), all the observations (approximately 1200) have been made by Dominion Observatory personnel.

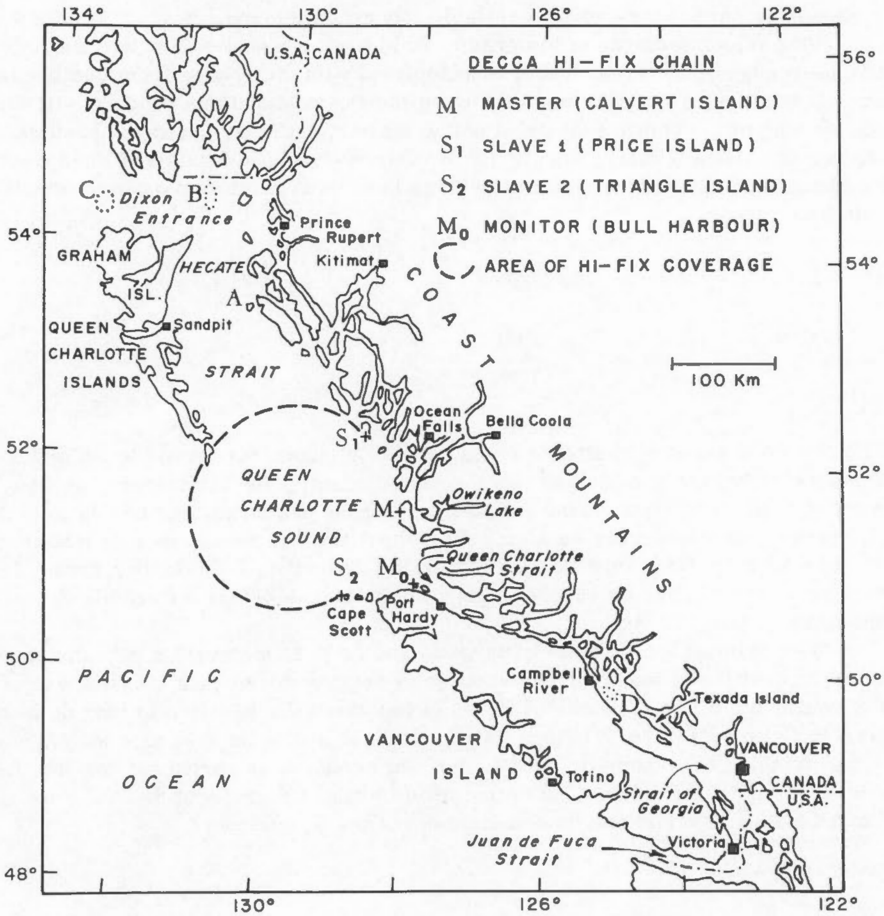

Figure 1. Sketch-map showing locations and Hi-Fix coverage. A - Bonilla Island, B - Celestial Reef, C - Learmouth Bank, D - Montgomery Bank.

In subsequent sections of this report the fieldwork and the instruments and techniques used are summarized and the reduction of the instrument readings to Bouguer anomalies and the special problems of calculating the terrain corrections are outlined. This is followed by a brief description of the geology and a summary of the interpretation of the gravity field published elsewhere (Stacey and Stephens, 1969).

FIELDWORK

General

The personnel and the instruments they used each year, the areas covered and the nature of the various surveys are summarized in the accompanying table.

Base Station Network

The gravity value at each control station is based on a value of 980.6220 gals for the National Reference Pier in Ottawa. Vancouver, Victoria, Campbell River and Prince Rupert are part of the National Network and the remaining bases are part of the British Columbia network. Temporary bases were established on the Queen Charlotte Islands, on the mainland coast near Ocean Falls and on northern Vancouver Island in 1967 while establishing gas caches for the helicopter. LaCoste and Romberg gravity meters were used for all the main ties except in southern Vancouver Island where a Worden gravity meter was used by Walcott (1967). The main bases and the ties between them are shown in Figure 2. The underwater gravity surveys are tied to the land network at Victoria, Kitimat and Prince Rupert (Figures 1 and 2).

Base station descriptions are listed by National Topographic System 1:1,000,000 sheets and can be obtained on request from the Gravity Division, Dominion Observatory, Ottawa, Canada.

The Gravity Measurements

Roads in the area of the survey are few except in southern Vancouver Island and on the lower mainland around Vancouver. Elsewhere de Havilland Beaver or Cessna 182 and 185 amphibious aircraft had to be used. During the 1967 land survey a float-equipped Bell 47G2 helicopter was used on the Queen Charlotte Islands and later in the season, when the machine was not required to service the Decca Hi-Fix navigation system (see Horizontal Control (page 5) and Figure 1), it was used for gravity surveying on northern Vancouver Island on the adjacent mainland. A Bell 47G4 and a Hiller 12E were used in the vicinity of Prince Rupert and Campbell River respectively to finish the surveys in these areas. A Canadian National Railway track inspectors railcar was used to reach the geodetic benchmarks (see Vertical Control (page 6)) along the railway line to Prince Rupert. Besides the gravity meter, the observer carried a pair of Wallace and Tierman barometric altimeters and collected a rock sample at each station where possible.

For the underwater gravity survey the Defence Research Establishment (Pacific) ship CNAV Laymore was used in both 1966 and 1967. The underwater gravity meter winch was mounted on the port side of the maindeck and the instrument was lowered over the starboard rail of the ship. The remote control levelling and reading equipment was kept in the maindeck laboratory from which the operator could instruct the winchman by either voice or hand signals. With this arrangement the ship's officer responsible for holding the ship on station while the instrument was on the bottom also had a good view of the winchman and the cable as it ran through the block and over the side of the ship.

SUMMARY OF FIELD WORK BY DOMINION OBSERVATORY PERSONNEL (1960-67)

Year	Area	Period	Working Days	Personnel	Transport	Inst.	Control Stns.	Detail Stns.
1960	S. Vancouver Island	Dec. 9-16	7	A.K. Goodacre	Car	W546	35	47
1963	Qu. Charlotte Is.	Aug. 6-	25	J.G. Tanner	Float plane	G9	26	
	Vancouver Is.	Sept. 2		J.B. Boyd	Car	W35		193
	mainland							
	Note: Only 6 days within area covered by this report, 5 control and 70 detail stns. established.							
1966	Qu. Charlotte Is.	May 21-	75	R.A. Stacey		G9	65	
(land)	northern mainland	Aug. 23		P. Fernandez-	Float plane			
				Davila	Stn. wagon	W431		1370
				J. Buchan	Jeep			
				T. Dean	Rail car			
	Note: Only 3 days within area covered by this report. 34 detail stns. established.							
(under-	Dixon Ent.	Aug. 30-	17	B.G. Brulé	CNAV	G25A	-	234
water)	mainland fiords	Sept. 22		R.A. Stacey	"Laymore"	H2G		
	Qu. Charlotte Str.			L.E. Stephens				
	Str. of Georgia							
1967	Qu. Charlotte Is.	July 28-	28	R.A. Stacey	Stn. wagon	G75	15	
(land)	northern mainland	Sept. 14		P. Fernandez-	Truck			
	Vancouver Is.			Davila	Helicopter	W546		393
					Float plane			
(under-	Hecate Str. Qu.	Aug. 16-	23	R.V. Cooper	CNAV	G25A	-	316
water)	Charlotte Snd.	Sept. 11		L.E. Stephens	"Laymore"	H2G		
	west of Vancouver Is.			J. Panar				

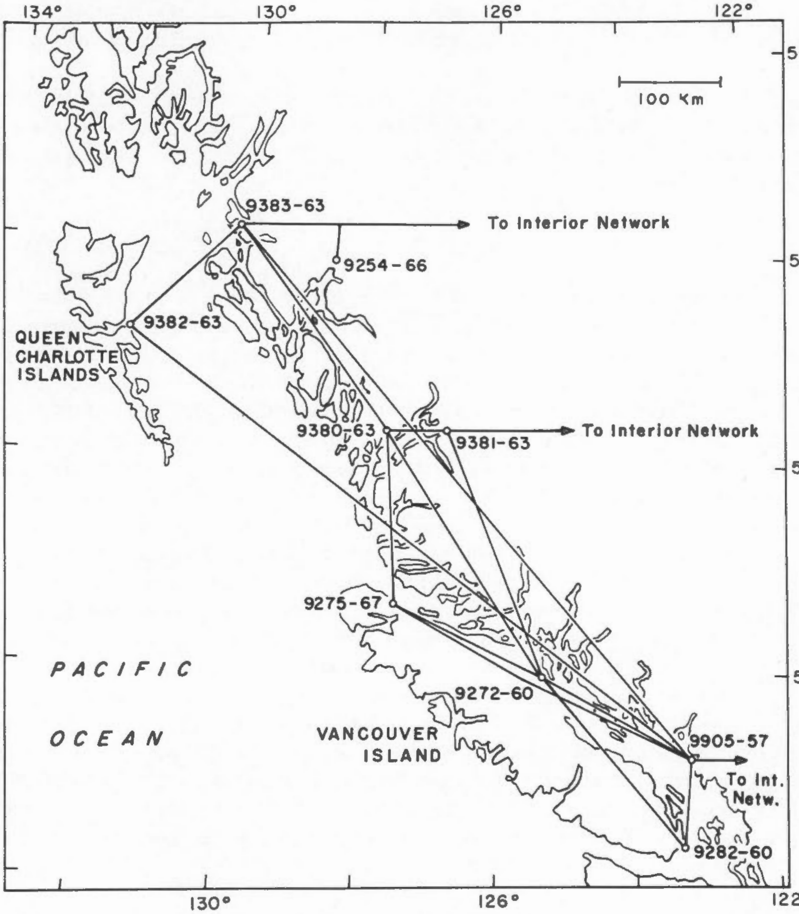

Figure 2. Base station network.

Horizontal Control

On land the position of each observation point was determined from the 1:250,000 topographic maps published by the Federal or Provincial governments. In areas where measurements were taken along roads the 1:50,000 maps were used if available. The estimated accuracy of these positions is ±0.1 km. During the underwater gravity surveys the ship's position was generally established by radar bearings and plotted on the largest scale nautical charts available. This method can give accuracies comparable to that of the land surveys when the ship is in the fiords or within 30 km of the coast. At distances greater than 30 km in Hecate Strait dead reckoning had to be used. In 1967 a Decca Hi-Fix navigation system was used to give the ship's position in Queen Charlotte Sound and the approximate area covered by this chain is shown in Figure 1. The Master Station was established on Calvert Island (51°36'N, 128°09'W) with Slave 1 on Price Island (52°16'N, 128°40'W), Slave 2 on Triangle Island (50°52'N, 129°05'W) and a monitor station at Bull Harbour (50°55'N, 127°56'W). These positions are shown in Figure 1. The equipment was borrowed from the Polar Continental Shelf Project and operated under contract by Computing Devices of Canada employees. The transmitter station positions were provided by Shell Canada Ltd. and correspond to their Chain 4.

Vertical Control

The only first order vertical control (geodetic benchmarks) in the area is along the Canadian National Railways into Prince Rupert, along the road into Bella Coola from the interior of the province, along the road which follows the east side of Vancouver Island and on the lower mainland in the vicinity of Vancouver. Elsewhere, readings were taken whenever possible at sea level during the land survey - usually between the high and low water marks. The tidal range is generally about 10 feet except in the fiords where it increases to 20-25 feet (Pacific Coast Tide and Current Tables published by the Canadian Hydrographic Service). Thus, if the observation point is between high and low water, it is generally within 10 feet of mean sea level. For points away from the sea, elevations given on the topographic maps for peaks and lakes were used whenever possible. If these were not available the Wallace and Tiernan altimeters carried by the observer were used, with readings at known elevations at intervals of one hour or less. The observer also tried to keep the difference in the control elevations and that of the unknown point to less than 300 m.

During the underwater survey an Edo echo-sounder and a pressure gauge on the water-tight housing of the gravity meter were used to measure the water depth at each station. Depths from the Edo have been compared with those from the pressure gauge and the standard deviation for measurements made during the 1966 survey is 8.4 pressure gauge units, equivalent to approximately 2.6 feet. This scatter is probably due to unevenness in the seafloor which is not identifiable on the echo-sounder. No corrections have been made for tidal changes.

REDUCTION OF THE OBSERVATIONS

Land Measurements

The calculated gravity value at each observation point was corrected to sea level assuming the normal free air vertical gradient of gravity (-0.3086 mgal/m). The difference between the resulting value and the theoretical value of gravity for the latitude of the observation (based on the International Gravity Formula of 1930) is the free air anomaly. For the Bouguer anomaly a further correction for the attraction of an infinite horizontal slab of rock, density 2.67 g/cm^3, between the observation point and sea level was made. The terrain correction necessary for the complete Bouguer anomaly reduction is discussed later in this section.

Underwater Measurements

The observed gravity value at a station on the sea floor was first corrected to sea level using the normal free air vertical gradient of -0.3086 mgal/m and then the attraction of the layer of sea water above the instrument was removed assuming it to be in the form of an infinite horizontal slab with a density of 1.03 g/cm^3. The gravity value as it would be observed at sea level is then obtained by replacing the infinite horizontal slab of sea water below the surface equivalent of the underwater station. The difference between this value and the theoretical value of gravity at the latitude of the observation is the free air anomaly. For the Bouguer anomaly a further correction was made for the mass deficiency of the sea water, density 1.03 g/cm^3, with respect to rock of standard density 2.67 g/cm^3. Terrain corrections to the underwater measurements were made only to those observations taken in the fiords of the mainland and these are discussed below.

Terrain Corrections

Three methods have been used to compute the terrain effects, the particular method used depended on the scale of the topographic maps available in the vicinity of each observation point.

(a) Prism method (Nagy, 1966). The topography in the vicinity of the station is divided into vertical rectangular prisms, the height of each prism being the difference between the elevation of the observation point and the elevation at the centre of the prism. The grid is based on the Universal Transverse Mercator (UTM) system and an area 50 x 50 km centred approximately on the station is divided into prisms 1 x 1 km. In the immediate vicinity of the station, an area 3 x 3 km is subdivided on a grid 200 x 200 metres to give a better representation of the topography close to the reading point. Within this area the elevation at the corner of each grid square is read from the map and the elevation of the enclosed prism is the mean of these four heights.

The elevations for the one kilometre grid are picked from 1:50,000 topographic maps and stored on punched cards or on magnetic tape and can be used repeatedly with different station points within the area of the data. This method is not used unless the available maps are at a scale of 1:50,000 or better as the elevation data for larger scale maps are not sufficiently accurate to be worth preserving. The 200 metre grid data are not stored because they are generally relevant to only one station.

When the station is near the boundary of a UTM zone, the terrain effect at the station for prisms in zone 'A' (which contains the station) is computed in the usual way. Partial prisms, resulting from the coverage of adjacent UTM zone, for which an elevation is available are assumed to be complete. The co-ordinates of the station are then computed for the adjacent zone 'B' and the terrain effect of the prisms in zone 'B' is added to that for those in zone 'A'. If the station is more than 1.5 km from the edge of the zone the error introduced by using partial prisms is negligible. When the station is within 1.5 km of the zone boundary Bible's tables are used to compute the terrain effect of the 3 x 3 km area around the station (see third section, on Combination of Nagy and Bible methods).

(b) Cylinder method (Bible, 1962). The topography in the vicinity of the station is divided into segments of vertical cylinders, the height of each segment being the difference between the elevation of the observation point and the mean elevation of the terrain within the segment. Bible has prepared tables giving the effect of segments of standard size and various heights within 22 km (zone M) of the observation point. This technique has been used when the available map coverage is at a scale larger than 1:50,000 or when the observation point is underwater and surrounded by extremely rugged topography, as along the fiords of the mainland. In this latter case the height of the land segments (area 1, Figure 3) is estimated from 1:250,000 topographic maps and is relative to the station elevation, although the observation point is below sea level. The effect of the land covered by water (area 2) and of the water (area 3) is assessed in the same way using nautical charts and a density of 1.03 g/cm^3 for sea water. After the effect of all the land and water above the observation point has been removed, the underwater gravity value is corrected to sea-level assuming the normal free air gradient to give the free air anomaly. The Bouguer anomaly is found by adding to this value the effect of an infinite horizontal slab of density 2.67 g/cm^3 and thickness equal to the depth of the instrument below sea level.

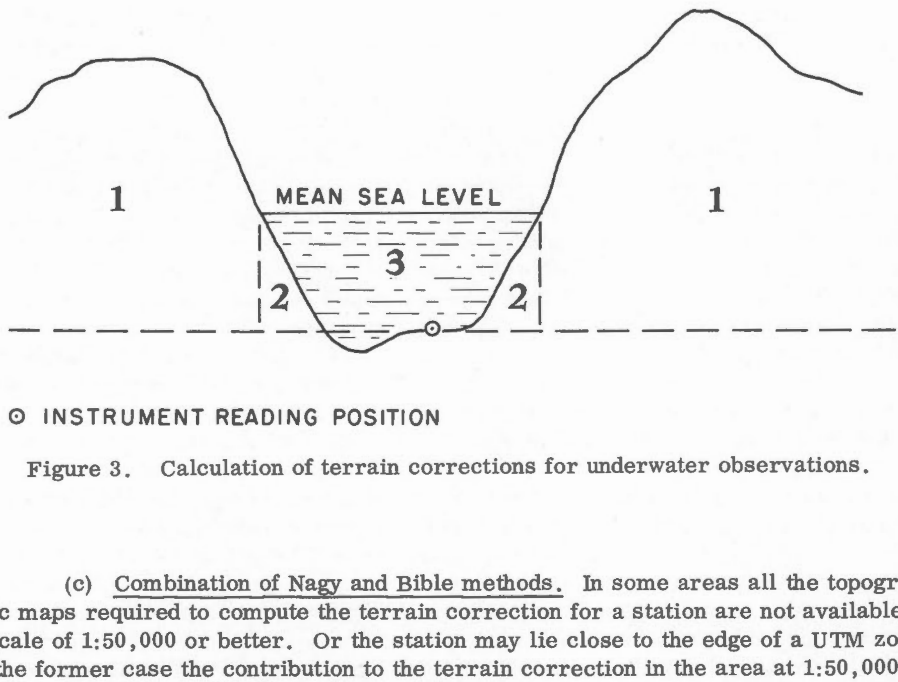

Figure 3. Calculation of terrain corrections for underwater observations.

(c) Combination of Nagy and Bible methods. In some areas all the topographic maps required to compute the terrain correction for a station are not available at a scale of 1:50,000 or better. Or the station may lie close to the edge of a UTM zone. In the former case the contribution to the terrain correction in the area at 1:50,000 or better is computed by Nagy's method and the effect of the terrain in the area covered by the larger scale maps is computed using Bible's tables. In both cases the area of an incomplete segment is expressed as a percentage of the complete segment and this percentage of the contribution for the complete segment is taken for the partial unit.

In the vicinity of Prince Rupert the topography is extremely rugged and it was decided that the 200 m grid normally used to represent the topography close to the station was inadequate. As picking elevations at an even smaller interval would be too time consuming, it was decided to compute the effect of the terrain in the 3 x 3 km area around the station using Bible's tables. As in the areas of incomplete 1:50,000 coverage, the contribution of the partial segments was assessed on the basis of area.

Principal Facts

The estimated accuracy of the Bouguer anomaly values after the addition of the terrain correction is ±5 mgal and consequently Gravity Map No. 88 has been contoured at 10 mgal intervals. This uncertainty is greatest in the fiords of the mainland where the terrain corrections are based on a combination of topographic maps at 1:250,000, with contours at intervals of 500 feet, and nautical charts at scales ranging from 1:30,000 to 1:75,000 with the depths shown in fathoms at isolated points.

Principal fact listings (giving the station numbers, their latitude and longitude, elevation or depth and the free air and Bouguer anomalies) can be obtained on request from the Gravity Division, Dominion Observatory, Ottawa, Canada.

GEOLOGY

The area covered by the gravity survey can be divided into two northwest trending structural highs, the Coast Mountains on the mainland and Vancouver Island and the Queen Charlotte Islands off-shore, with a depressed area which includes Hecate Strait, Queen Charlotte Sound, Queen Charlotte Strait and the Strait of Georgia in between (Figures 1 and 4). The Coast Mountains are a complex of plutonic and metamorphic rocks, ranging in composition from gabbro to granite (Roddick, 1966). Potassium-argon dates suggest that the majority of the plutonic rocks were emplaced during the Late Cretaceous and Early Tertiary.

On Vancouver Island and the Queen Charlotte Islands, Mesozoic volcanic rocks up to 3 km thick predominate (Brown, 1966). These rocks have been intruded by diorite and granodiorite ranging in age from Jurassic to Tertiary. Late Cretaceous or Tertiary sedimentary basins occur on the east side of Vancouver Island in the northern part of the Strait of Georgia and in Queen Charlotte Strait. Similar basins are suspected farther north in Queen Charlotte Sound and Hecate Strait. West of Vancouver Island Tertiary sediments are exposed along the shoreline and may extend to the edge of the continental shelf 60 km to the west. West of the Queen Charlotte Islands there is no shallow area which could be regarded as the continental shelf although there is a comparatively flat area about 40 km wide at a depth of 1600 m which may be the equivalent structure.

The major faults in the area are parallel to the dominant northwesterly trend and are shown in Figure 4. There is a pronounced east-west trend across southern Vancouver Island which can be related to east-west faulting and a similar east-west trend in the Coast Mountains at the same latitude as the northern end of Vancouver Island. However, this latter trend cannot be related to any geological feature at present (Hutchison, personal communication).

At the northern end of the area in the vicinity of Dixon Entrance the northward dipping Palaeozoic rocks of southeast Alaska cannot be related to the Mesozoic and younger rocks seen along the northern shores of the Queen Charlotte Islands.

All the available density measurements have been given by Stacey and Stephens (1969) and will not be repeated here.

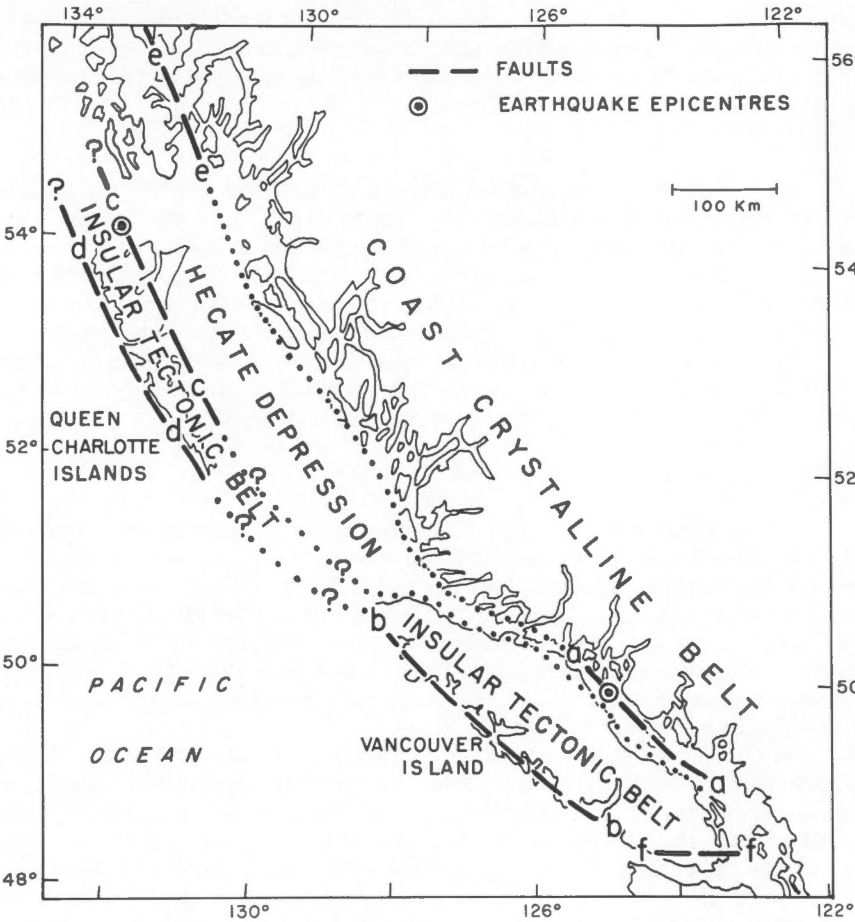

Figure 4. Structural sketch-map of the coastal area of British Columbia.

GENERAL DESCRIPTION OF THE BOUGUER ANOMALY FIELD

The dominant trend of the Bouguer anomalies is northwesterly, which is parallel to the major geological structures. Although this trend is clear on Gravity Map No. 88, few anomalies extend across the whole area so the southern part of the map will be considered first, followed by the northern part.

There is a decrease in the Bouguer anomaly values west of Vancouver Island over the continental shelf which indicates the presence of a considerable thickness of light sedimentary rocks. The undulating field over Vancouver Island, with Bouguer anomalies ranging from -30 mgal to +30 mgal, can be related to variations in the density of the surface rocks. The east-west anomaly with Bouguer values of +60 mgal at the southern end of Vancouver Island can be related to east-west trending basic volcanic rocks. However, the very similar high at the northern end of the Island cannot be related to the surface geology, although there is a pronounced east-west physiographic trend on the mainland at the same latitude.

In the northern part of the area the Bouguer anomaly field rises to +70 mgal over the Queen Charlotte Islands, obscuring any possible correlation with the surface geology. These high values may reflect a rise in the Mohorovicic discontinuity towards the Pacific Ocean. Over Hecate Strait and Queen Charlotte Sound the field varies between -20 mgal and +20 mgal and is believed to reflect variations in the thickness of the sediments. The distinctive local highs of 40 mgal or more superimposed on the undulating background field probably coincide with thick sequences of basic volcanic rocks.

The rapid decrease in the gravity values to less than -100 mgal toward the centre of the Coast Mountains throughout the area begins very close to the physiographic boundary between the comparatively low-lying coastal area and the high ground of the Coast Mountains. Both the coastal lowland and the Coast Mountains appear to be part of the Coast Crystalline Belt and there is no measurable change in density between the coastline and the axis of the Coast Mountains (Roddick, 1966) which could account for the change in the gravity values. Therefore, the increasingly negative values of the Bouguer anomaly eastwards are tentatively assumed to reflect a thickening of the Earth's crust below the Coast Mountains.

ACKNOWLEDGMENTS

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