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OF
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Institute
of
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Department of Fisheries and Oceans
Director General's Foreword

This review is the fourth in the new series of IOS Annual Reviews. We have stayed with a review that sets out our main accomplishments throughout the year in a simple fashion, as we believe such a document should be generally available. Without conducting a survey, the comments we have received have been complimentary and we intend to continue with similar reports in the future.

I do not wish to dwell on any of the programs we have undertaken during the year but do want to comment on a trend that has appeared in physical oceanography. This trend is the increasing number of researchers in other fields who are finding they cannot make progress with the problems they are endeavouring to solve without improved information about the physical characteristics of the ocean. The problem of climate prediction is the outstanding example. The same trend is apparent in attempts to improve the operational forecasting of waves, sea ice, etc. Research in physical oceanography is becoming driven by demand. Fifteen years ago this was not the case, and the majority of research in physical oceanography was exploratory and driven by the desire to improve knowledge of the oceans.

Over the same period of time there has been almost a revolution in the instruments available to the physical oceanographer. The new instruments make it possible to provide vastly improved descriptions of ocean phenomena and have stimulated much theoretical work. Ocean models have now become commonplace, whereas a few years ago they were worked on by only a few interested scientists. They are being constructed on all scale sizes and are being applied to obtain an insight into how the ocean works and to practical problems. I believe this trend is accelerating and that over the next 10 years the funds and the number of physical oceanographers engaged in research will have to be increased if the demands are to be met. Not only will the research have to be increased, it will also be necessary to provide equipment and dedicated people to undertake operational forecasts. Together, these mean a substantial increase in the physical oceanographic community. At the Institute of Ocean Sciences, we will concentrate on climate problems and on forecasting techniques for waves, ice motion, and coastal currents. These are natural directions in which to develop the I.O.S. research program and I hope that we will be able to expand the program in the future.
HYDROGRAPHY
Pacific Region 1984 hydrographic survey program
Hydrography

The hydrographic program at IOS includes field hydrography, tidal and current surveys and chart production and distribution. The primary objective of the program is to provide accurate, timely bathymetric and navigational information in the form of nautical charts, tide tables, current atlases and sailing directions. These publications and supplemental information are provided to a variety of clients including mariners, commercial fisherman, sports fisherman, recreational boaters, engineering and consulting firms, other federal government agencies and the general public.

Also covered in this section is Engineering Services, which provides support for hydrographic surveys, oceanographic research and ship operations, in the form of electronic/mechanical engineering and electronics. A major component is an industrial liaison service promoting interaction among IOS, other government departments and the private sector.

Field Hydrography

The Field Hydrography Section is responsible for conducting hydrographic surveys of the British Columbia coast, western Arctic and navigable inland waters in the Pacific Region in order to ensure that the requirements for navigational information are met. Alterations of, and additions to traffic routes, types and sizes of vessels, harbours, bottom topography and coastlines—all require an ongoing and resurvey program.

A major survey party was mounted for a survey of the Shuswap Lake system, a major recreational boating area in the B.C. interior. This survey was completed. *(Contact: B.M. Lusk.)*

An eight-week survey of the northeast coast of the Queen Charlotte Islands from Lawn Point to Rose Spit was carried out by a party operating from
CSS Parizeau. Existing charts of the area are based on surveys of 1911-1918. (Contact: B.M. Lusk.)

On the Shuswap Lake survey

A second major coastal survey party completed a survey of the Hardwicke Island region and then moved to the uncharted Fish Egg Inlet area. At the end of the season the uncharted head of Boswell Inlet, Wychees Lagoon and Draney Inlet were surveyed and Smith and Naysash Inlets were resurveyed to modern standards. (Contact: A.R. Mortimer.)

A small party onboard CSS Richardson completed large scale surveys of Uganda Passage and Roscoe Bay for a projected chart atlas of the Desolation Sound area. (Contact: G.H. Eaton.)

In the Queen Charlotte Islands, a CSS Richardson party continued surveys of Skidegate Channel, completing Trounce Inlet, the west narrows and Armentieres Channel. A continuing survey of Quatsino Sound was completed. (Contact: J.V. Crowley.)

Shore based parties carried out the following small projects: a survey of Robbers Passage, Barkley Sound (Contact: J.V. Crowley); completion of the survey of Ridley Island Terminal where construction equipment had precluded completion in 1983 (Contact: J.V. Crowley); and a large scale survey of Westshore Terminal at Roberts Bank where a new loading terminal had been constructed and dredging had taken place in the turning basin. (Contact: G.E. Richardson.)
In the western Arctic, survey control was strengthened in the Herschel Island to Banks Island area. A multi-disciplinary survey under contract to Cansite Surveys Ltd. of Calgary was carried out between the Alaska/Yukon boundary and Herschel Island and after a slow start due to poor ice conditions the bathymetric portion was completed during a late ice opening in September. (Contact: G.H. Eaton.)

Surveys for sailing directions and chart revisions were carried out under contract to Coast Pilot Ltd., Sidney. A revisory inspection for the Pitt River chart was completed by staff. (Contact: G.E. Richardson.)

**Sailing Directions**

The Thirteenth Edition of *British Columbia Coast Sailing Directions (South Portion)*, Volume I was published in December. This edition contains new information on tidal streams, vessel traffic services and port facilities. New photography and several new diagrams were incorporated into this edition. Volume I and Volume II (North Portion) are published in alternate years. (Contact: Volume I, A. Smith; Volume II, J.W. Roberts.)

*Small Craft Guide, Volume II (Boundary Bay to Cortes Island)* Fifth Edition was published in May. (Contact: L.M. Chan.)

Field inspections for revisions were carried out on the Mackenzie River and the B.C. coast.

**Hydrographic Development**

Hydrographic data processing software was enhanced this year by an improved multi-range positioning solution and an improved data cleaning package. Hydrographic Acquisition and Logging (HAL) data loggers and processing software were fully tested prior to the field survey on CSS Parizeau. HAL loggers have completely replaced the older PHAS (Portable Hydrographic Acquisition System) units for hydrographic data collection in the region.

Two Unsolicited Proposal contracts were completed this year. A hydrographic contouring package was delivered in June and full testing was applied on the Parizeau data during post-cruise analysis. Test conclusions are not yet available.

Also in June, hardware and software were received to digitize and plot shoreline and control from aerial photographs. The equipment is compact
and portable enough to be ship or field office based, and was used on the Shuswap Lake survey.

As a result of a contract, Liquid Crystal Display (LCD) remote readouts were developed and supplied for Trisponder 540, mini-ranger and mini-ponder type positioning systems. They greatly enhance visibility in high ambient light conditions and enable greater flexibility in instrument package siting in smaller boats. Several field parties used the remote readout units. (Contact: J.B. Larkin.)

Chart Production and Distribution

The functions of the Chart Production and Distribution Section are to ensure that survey and other data are processed for publication as expeditiously as possible and to ensure that a ready supply is available for all users.

Ten new standard charts were produced in Pacific Region this year in addition to 64 new editions and 14 reprints. A heavy load of hand amendments (1.3 million on 160,000 charts) precipitated the preparation of 14 overprintings and 11 chart amendment patches were required. The Chart Sales office distributed 161,534 charts, 77,314 publications and 32,136 information brochures during the year.

Fifteen Notices to Shipping and 155 Notices to Mariners were issued, necessitating 191 chart amendment tracings, and 1304 MAREP (the Canadian Power Squadron’s Marine Reporting Program) reports were processed.

Four staff attended CARTO I and three senior staff attended the CARTO II training program.

One year has now passed since the VAX 11/750 came on line. All the software required to process a digital chart file is now in place. Disk-to-disk processing and the faster operating speed of the VAX has resulted in a decrease of approximately 30% in file handling and processing time. With digitizing, editing (GOMADS) and file processing all able to operate
simultaneously the VAX has more than doubled digital chart production capacity.

Promotional and educational activities continued with participation in two boat shows. Other activities included tours and lectures for Canadian Power Squadrons and university students.

A DEC Rainbow 100 computer was purchased for the Chart Sales and Distribution office, replacing a Radio Shack TRS 80 computer. Acquired primarily for accounts receivable and inventory control, it is also proving to be an effective tool for the planning and scheduling of the chart amendment program.

The cancellation of Chart 3450, East Point to Sand Heads, in September marked the end of an era in the history of charting west coast Canadian waters. First published in 1937, it became one of the best selling charts in Canada and a standard aid used in navigation courses, including those operated by the Department of Defence, Canadian Power Squadron and numerous sailing schools.

**Tidal and Current Surveys**

A study of the circulation in the waters surrounding the Queen Charlotte Islands, which began in 1982 in Queen Charlotte Sound, was extended into Hecate Strait, to the west coast of the Queen Charlottes (in collaboration with Ocean Physics Division), and further into Dixon Entrance. Cruises were mounted in January, April and in October. Losses of some current meter moorings were sustained due to fish boat interference near the Alaska coast. To provide data for numerical modelling of the area, 10 near-shore bottom pressure gauges were deployed, including three near the Alaska coast. Much of the instrument data processing was done at sea allowing some preliminary analysis to be carried out before the moorings were redeployed. (Contact: W.S. Huggett.)

Complementary to the moored instrument survey, a surface drifter study was carried out under contract for a period of two weeks in July. This was the first full field trial for the Loran-C telemetering drifters and, despite a few problems, enough data was collected to show the main features of the surface currents. (Contact: W.R. Crawford.)
The current meter data gathered during the 1982 and 1983 field seasons in Queen Charlotte Sound and Hecate Strait reveal a circulation pattern dominated by the winds. In Queen Charlotte Sound in summer, winds from the northwest tend to push the fresh water out of the Sound over Cook Bank, past Cape Scott and into the Pacific Ocean. During southeast winds, the fresh water is confined to the eastern side of Hecate Strait and Queen Charlotte Sound, flowing to the northwest. The 12 months of current meter data from Hecate Strait reveal that in winter, when the prevailing winds blow strongly from the southeast, most of the river runoff is swept into Dixon Entrance, although a portion of this water appears to flow southward along the eastern side of the trench running along the Strait. Average currents observed in four separate months are illustrated. The pattern of currents described above shows clearly in November and February. In May and August the strong southeast winds abate, to be replaced by calmer weather with prevailing winds from the northwest. Consequently, currents are weaker and tend to flow to the southwest along
the sides of the Strait, with a return flow in the centre of the channel. Models of this circulation are being developed in an attempt to predict the northward transport of fresh water under different wind and runoff conditions. (Contact: W.R. Crawford.)

A current survey in Nakwakto Rapids and at several sites in the Seymour Inlet complex was completed in order to improve predictions in these fast-flowing narrows. The method used in Nakwakto Rapids involved the measurement of along-channel pressure gradient over a period of one year in order to extend the short series of current observations. Software development to determine the necessary empirical models, to form the extended time series and to compare the results with existing predictions and historical data is nearing completion.

Comparison of 10 different types of current meter, the field work for which concluded in September of last year, was substantially completed. This study shows that noise to signal ratios of 10 are not uncommon for current
meters suspended close below a surface float. There is considerable variation in the performance of different instruments under these conditions. *(Contact: M.J. Woodward.)*

Continuing previous practice, tidal records from 21 permanent, five temporary and several hydrographic stations were processed and the data forwarded to Marine Environmental Data Centre for archiving. Data from three Pacific coast tide stations are being forwarded each month to IGOSS as Canada's contribution to a Pacific mean sea level anomaly study.

A study of mean sea levels on the west and east coasts of central Vancouver Island was continued. This work is being done at the request of the Pacific Geoscience Centre as part of a program to measure and study earthquake induced crustal movements.

Work continued on hardware and software for two Meteor Burst tide stations. After testing and evaluation this unit will be installed at Queen Charlotte City. *(Contact: F.E. Stephenson.)*

The measurement of tides and long-term mean sea level variations in the Queen Elizabeth Islands continued. The three stations on the Arctic coast of the archipelago were serviced in May and Pond Inlet was visited in August. Two bottom-mounted pressure recorders are now installed at each of the four sites. This study is being supported in part through funding from HARP (High Arctic Research Program).

The bottom-mounted pressure recorders at the five permanent stations in the western Arctic were serviced and redeployed in July and August. Analog bubbler gauge stations are also being maintained at Tuktoyaktuk and Cambridge Bay.

A pressure recorder installed at Baychimo in 1983 to determine mean sea level at that location for Geodetic Survey of Canada was serviced and redeployed for one more year. *(Contact: F.E. Stephenson.)*

**Campbell River Estuary**

At the request of the Pacific Biological Station, a year long study of the Campbell River Estuary started in July 1984. The study involves measurements of tides, currents, salinities and temperatures throughout the four seasons and at a variety of tides and river discharge states. The study is
being carried out in close cooperation with fisheries scientists. The objective is to discover how an environmental enhancement project carried out by B.C. Forest Products Ltd. might affect salmonid feeding grounds. The project will include a numerical tidal model including, if possible, the salinity intrusion.

**Fraser River Estuary**

Participation in the development of a Federal-Provincial program of long-term environmental monitoring for the Fraser River estuary continued until the fall of 1984 when a final report, “Fraser River Estuary Monitoring – A Recommended Approach”, was submitted to Environment Canada and to the Department of Environment, Province of British Columbia.

Production runs of the Fraser River numerical model continued throughout the year to assist such interests as shipping on the lower reaches of the river, construction projects and various court cases.

Current, salinity and temperature measurements continued in the trifurcation area and in the reaches leading to Canoe Pass. Detailed time series were conducted in the vicinity of the construction site of the new bridge crossing the Fraser at Annacis Island.

**Skeena River Estuary**

A helicopter survey of salinities, temperatures and currents in the lower part of the Skeena River was conducted in the early spring. This survey suggested the development of a portable instrument which could measure and record a variety of estuary features from a helicopter or hovercraft. *(Contact: A.B. Ages.)*

**Diving Unit**

By far the most common diving activity in 1984 was the placement and/or recovery of bottom mounted pressure gauges at various sites on the Pacific coast and in the western Arctic. In excess of 20 locations were visited during the year. This work was done for programs being conducted by Ocean Physics Division and Tidal and Current Surveys.
Divers also carried out several propeller inspections for the *Parizeau* and assisted in the recovery of weather buoy moorings in Dixon Entrance and at the entrance to Juan de Fuca Strait.

Closer to home, divers assisted the Ocean Physics group in the design of a bracket to attach two transducers to the keel of the *Vector*. This unit was used to measure lateral movement in struts supporting an echometer system. *(Contact: F. Stephenson.)*

*Surfacing after tide gauge deployment at Coppermine, N.W.T.*

**Engineering Services**

Engineering Services provides electronics and mechanical engineering and electronics support for hydrographic surveys, oceanographic research and ship operations and an industrial liaison service promoting interaction between IOS, other government departments, and the private sector. *(Contact: T.A. Curran.)*
Engineering Development

This group provides custom development of hydrographic and oceanographic instrument systems, management of government-funded contracts and consultations to all IOS groups.

Instrumentation projects completed in 1984 included a portable current meter, a Meteorburst tidal telemetry system and development of a sensor for measurement of zooplankton populations. A pressure test facility, capable of operation to an equivalent depth of 6000 metres, was brought into full operation.

The Active Drifter hardware underwent additional testing with successful trials of the station-keeping navigation sub-system and implementation of power management hardware. Local contracts involving the Active Drifter included development of an efficient and reliable thruster and a detailed engineering study of UHF antennas. The Active Drifter concept was presented to the engineering community at PACON 84.

An increasing level of effort is being directed to the application of acoustics with the construction of a number of standard electronic modules for hydrographic and oceanographic applications. Mechanical components for an in situ acoustic calibration facility were constructed and installed at IOS and this facility was used to calibrate and test components of the acoustic video telemetry system. A study was undertaken to identify methods by which the depth capability of launch sounders could be extended. Modifications were made to the IOS-developed Sterntow sounder electronics to facilitate use of different transducers in the Atlantic.

Significant engineering support was provided for the Pisces IV program with the purchase and installation of an ultra-short baseline acoustic navigation system and subsequent novel modifications to the support vessel's ram which gave additional maneuvering freedom. A suite of scientific tools developed under contract were installed on the submersible.

The group's contract management responsibilities include supervision both of complete instrumentation development contracts and of smaller contracts which augment “in house” developments. The year saw completion of the shipboard version of the correlation sonar current meter development contract. Contracts for development of unique solar panels and an equally unique acoustic release mechanism were nearly completed and encouraging results were achieved with the laser diode pressure sensor.
contract. An evaluation was completed of the SeaMARC II swath survey acoustic system which was tested off Vancouver Island. (Contact: r. Galloway.)

**Institute Electronics**

Calibration, repair, installation and routine maintenance of equipment in support of hydrographic and oceanographic programs and ship operations were successfully performed during the year. The major equipment areas were radios, depth sounders and digitizers, positioning systems and data loggers.

In the communications area, approximately 65 VHF-FM and 15 HF/SSB transceivers were maintained. A radio teletype system (TOR) was installed at IOS and interfaced to the HF radio station for direct hard copy text communication with Parizeau. Two Glenayre HF data message terminals were obtained for evaluation purposes, one at IOS and the other on Parizeau. Results to date are very encouraging and steps are being taken to gradually fit IOS vessels with terminals.

The sonar group maintained 28 survey type and navigational depth sounders as well as numerous small digital sounders and 12 sounder digitizers. In addition two velocimeters were serviced and maintained.

Approximately 21 microwave positioning units, 15 Argo units, two transit satellite navigation systems and several Loran-C and Omega systems were serviced.

All fine data logging systems received a thorough overhaul which included hardware and software changes.

Ships, launches and the barge Pender were fitted out for hydrographic purposes.

Field support was provided for hydrographic survey on Parizeau and local support was provided to local survey parties.

Continuing support was provided to Computing Services in the maintenance of the Kongsberg drafting system. (Contact: W. Ron Taylor.)
Industrial Liaison and Contracting

The Institute of Ocean Sciences has an established policy of conducting a significant portion of its program through contracts to the private sector.

In addition to contracting out directly, IOS participates in such government ventures as the Unsolicited Proposals (UP) program with the Department of Supply and Services (DSS), and both the Program for Industry/Laboratory Projects (PILP) and the Industrial Research Assistance Program (IRAP) with the National Research Council (NRC). IOS was involved to some extent in 116 contracts in the past year, ranging in value from less than one thousand dollars to approximately one million dollars, and with a total value in excess of $4.8 million. (Contact: T.A. Curran.)
OCEANOGRAPHY
Ocean Physics

Circulation and Climate

During 1984, three ocean climate monitoring cruises were made. This brings to 11 the number of cruises along Line P, the northern Line R, and other associated lines since the withdrawal of the weatherships from Ocean Station Papa. (Contact: S. Tabata.)

The characteristics of both the annual and interannual variability of steric height (the change in sea level due to the fact that a given mass of colder or saltier water takes up less volume than an equal mass of warm fresh water) off the Pacific coast of Canada, based on Line P data, can be grouped under three main categories according to their locations: open ocean (beyond continental slope), transitional region (continental slope) and coastal region (continental shelf to shelf edge). In the open ocean the temperature effect dominates the annual change of steric height whereas along the coastal region the salinity effect dominates. There is little evidence that the large-scale offshore circulation of the Subarctic gyre is relevant to the annual cycle of mean sea level along the coast. Precipitation and runoff, wind-induced transports and coastal currents appear to be important to the annual variation of coastal steric height. (Contact: S. Tabata.)

One of the obstacles to development of reliable large scale models of ocean circulation is the lack of understanding of exactly how eddies affect the exchanges of momentum, heat and salt. Eddies are known to be common in many parts of the ocean, and cannot be ignored. In view of the complex nature of the flow fields involved, theoretical studies often focus on statistical descriptions, analogous to those used in work on small scale turbulence. One way of evaluating the effects of an eddy field is to examine the changing distribution of particles in the field.

Numerical simulations of idealized oceanic (or atmospheric) eddy fields have been developed. They include large-scale mean gradients of a passive tracer (dye) and large-scale mean gradients of ocean current. The movements of particles (floats) can also be followed. Results show that the efficiencies of tracer transport and of particle dispersion are reduced with increased stratification or with increased change of rotation with distance. This suggests that eddy exchanges over the continental slope should be
inhibited. (Contact: G. Holloway.)

These models were applied to examine the relative importance of eddy stirring, spatial variations in the growth/decay rate, and lateral diffusion in maintaining spatial patchiness in phytoplankton biomass. As might be expected, the results depend on the time scales of growth/decay relative to those of eddy stirring; only when they were similar did the eddies have much effect on the spatial structure of patchiness. (Contact: G. Holloway.)

In a related study, numerical experiments were used to explore the factors controlling the stirring of plankton across a frontal zone paralleling the shore, in three types of current fields emulating those thought to exist over the continental slope. The most striking result shows that shelf waves tend to suppress the cross-frontal exchanges relative to either eddies which are locked to topographic features or eddies which self-direct along the coast. In all cases there is a rich, time dependent sequence of plankton patterns not unlike those observed in satellite images. The output from the model was used to generate a 16 mm colour film. (Contact: G. Holloway.)

Theoretical studies of dispersion processes stimulated an analysis of TWERLE high altitude balloon pair data (provided by the U.S. National Center for Atmospheric Research) and matching high altitude wind fields (provided by the Australian Bureau of Meteorology). These demonstrated that relative dispersion in large scale quasi-geostrophic turbulence, such as found in the atmosphere and ocean, is a non-local process. The shear in the most energetic eddies controls the relative dispersion on all smaller scales, so that particle separations grow faster than would otherwise be expected. (Contact: A. Bennett.)

Continental Shelf

The data collected off Vancouver Island during the Coastal Ocean Dynamics Experiment (CODE) between 1978 and 1983 continue to yield valuable results. Diurnal currents along the west coast of Vancouver Island were found to have the spatial structure expected of baroclinic continental shelf waves rather than the usual Kelvin wave. Continental shelf waves thus turn out to be important to investigation—a far cry from the theoretical curiosities they were originally thought to be! Off Brooks Peninsula the current gradients are large enough to lead to the formation of “eddies” 50 km in diameter, in which large pools of anomalously fresh water become detached from the northward flowing coastal current to
drift slowly southward along the edge of the continental shelf. The results of several recent experiments were combined to produce a general summary of seasonal currents off the southern B.C. coast.

The focus of efforts aimed at obtaining a preliminary description of currents on the west coast has now moved northward. An array of current meter moorings is being maintained west of the Queen Charlotte Islands and in Dixon Entrance until at least May 1985. (Contact: R.E. Thomson.)

The complex bottom topography typical of the B.C. coast has made it difficult to test theories regarding the low frequency continental shelf waves which might be one of the mechanisms by which disturbance generated by distant events, such as El Nino, can propagate to local waters. The continental shelf off East Australia is remarkably regular and smooth, which led IOS scientists to propose an experiment there to test the theories. The idea received an enthusiastic response in Australia and the U.S. with the result that an international current meter mooring array was installed for six months ending in March 1984. The IOS team had the best instrument (100%) and data (90%) recovery rate among the groups participating. Preliminary results show that continental shelf waves were observed, but that they propagate more slowly than expected. (Contact: H. Freeland.)

Ocean current and sea level observations from the Beaufort Sea Project of 1974-75 were examined for the presence of shelf waves. Existing theory on shelf waves was applied to the shelf geometry of this area to facilitate their identification in available data. Measurements of current at the shelf edge in the Beaufort Sea during 1981, which revealed strong semi-diurnal oscillations, were studied in light of existing theory on internal tides. Studies of 1981 observations revealing a shelf break undercurrent, and a freezing-driven thermohaline circulation continued. Modelling work on wind-driven barotropic circulation over the shelf was initiated using the shallow-water-equations model of Henry and Heaps, and simplified analytical representations of shelf circulations due to Csanady are being explored. (Contact: H. Melling, P. Budgell.)

The N.W. Passage oceanographic program continued with the collection of data in the region of Barrow Strait. These data were relevant to the description and understanding of tides, water structure and current velocity including year-long current information. Completion of the survey in 1984 entailed measuring 144 CTD profiles for the purpose of identifying water masses and baroclinic circulation. The CTD stations were concentrated in the waterways adjacent to Cornwallis Island,
although selected stations over a wider area in the Archipelago were revisited again. Two tide gauges and twenty current meters were deployed from the ice for a three-month period at 2 cross-sections in Wellington Channel and in Barrow Strait. Data from this survey, together with those from earlier years, have been processed and documented. (Contact: H. Melling.)

Long-term current, temperature and salinity measurements were continued in 1984 with the objective of documenting seasonal variability in the Arctic. A mooring deployed in April 1983 in Austin Channel was recovered in April 1984, with successful 12-month data records obtained from a seafloor pressure gauge and from 2 current meters. Efforts to recover 2 similar moorings in Barrow Strait, deployed by the Bayfield Laboratory in April 1983 were unsuccessful as the moorings could not be located despite attempts both in April and in September 1984. The moorings are presumed lost. Two additional moorings were deployed at nearby locations in Barrow Strait in April 1984. A further two moorings were deployed in Penny Strait in April 1984.

In an effort to understand the reasons for inflow of water into the Archipelago from the Arctic Ocean, moorings were deployed in April on its western periphery (2 in McClure Strait and 3 in Ballantyne Strait) in conjunction with sea-level measurements at Auldhild Bay, Isachsen and Mould Bay by CHS. Temperature and salinity measurements were also acquired on a section running northwest off the shelf into deep water. Tide gauge recoveries are scheduled for late May 1985. (Contact: E.L. Lewis.)

**Upper Layer Processes**

Field work for project SUPER (Subarctic Pacific Ecosystem Research) was carried out during May in conjunction with IOS Ocean Ecology and University of Washington scientists. The objective of this experiment was to determine why the Northeast Pacific is unique in having no spring plankton bloom. The physical oceanographers involved were responsible for obtaining measurements of the physical processes affecting the plankton during the experiment, which took place near Ocean Weather Station P (50°N, 145°W). A drifting instrument array was operated all through the experiment to provide meteorological data and a time history of water temperatures down to 200 metres depth. The FLY turbulence profiler was used to measure levels of turbulence, which can result in plankton being mixed down out of the zone of high light intensity. (Contact: A. Gargett.)
Observations over the last few years of near-surface waters under ice in the Arctic have frequently revealed a temperature depressed by as much as 0.01°C below freezing temperature. The existence of such supercooling is puzzling in the light of current understanding of the freezing of seawater. Moreover, it represents some capacity to grow ice should the supercooling be relieved. These observations stimulated the initiation of a laboratory experiment to grow ice in seawater under carefully controlled conditions of temperature and temperature gradient, and to observe the growth through still photography. Analysis of results is not yet complete. (Contact: E.L. Lewis.)

Forecasting Methods

Trials of the 2 km mesh computer models of the Georgia-Juan de Fuca Strait system confirmed earlier experience of the remarkable sensitivity of the modelled tides to adjustments of frictional dissipation. It became necessary to modify the computational scheme to include fractional mesh widths at a number of locations where flow restrictions occur. A successful calibration was achieved for the combined non-linearly interactive \( M_2 \) and \( K_1 \) tides. Using data sequences from the above trials as input, successful tests were made of an extended version of the buoyant spreading upper layer model used to include the effects of the Fraser River plume. (Contact: P. Crean.)

The original, overall tidal model was modified to incorporate prepared wind fields and observed sea levels on the southern open boundary for simulation of the December 1982 storm surge. For comparison purposes, a simulation of tides for that period was completed. A test simulation of the surge encountered some inconsistencies between U.S. and Canadian sea level datums to which gauge elevations are referred. (Contact: T. Murty.)

A linear superposition method was developed using independent component solutions for objective interpolation between observed tidal elevations inshore of the Queen Charlotte Islands. Satisfactory fits to the observed principal diurnal and semi-diurnal constituents were obtained and cotidal charts are being prepared. An irregular triangular grid model was also developed to permit better resolution than is possible with the finite-difference model. Preliminary work on the tidal currents was carried out during the study of tidal elevations. It was evident that spurious topographic waves generated during the spin-up to steady oscillation
conditions can mask the genuine tidal current field, a phenomenon not previously reported in the literature. (Contact: R.F. Henry.)

Several stages in the development of a finite-difference barotropic model of the Northwest Passage were completed. An irregular, triangular grid was developed which fits the coastline well and maintains an approximately constant area/depth ratio over all grid elements. Corresponding water depth data were assembled and certain modifications to Thacker’s finite-difference scheme required for this application were completed. Initial simulations of the M₃ tidal constituent indicate that the model is stable and calibration against tidal observations is proceeding. A graphics program was written to permit display of quantities computed on the irregular grid. (Contact: T.S. Murty.)

New requests from various countries for the tidal analysis package have brought the total distribution to 69 institutions worldwide. Numerous enquiries relating to the use of these programs were answered and the manuals were reprinted. (Contact: M. Foreman.)

In response to a request from Environment Canada, an existing numerical storm surge model of the southern Beaufort Sea was adapted for detailed study of extreme water levels at Tuktoyaktuk and surroundings. Extreme winds over the shelf, computed by Atmospheric Dynamics Corporation, were used to predict 100-year surge levels at Tuktoyaktuk. Seaconsult Marine Research computed maximum wave heights for the same extreme winds. The results of the surge and wave predictions were combined to produce a 100-year flood risk map which indicates that most of the village and airstrip would be submerged. However, confidence in this result is limited due to the inadequacy of historical water level observations. (Contact: R.F. Henry.)

Advisory and planning work on future programs on storm surges in the Bay of Bengal continued in response to specific requests from the World Meteorological Organization. A numerical model of the Arabian Sea was developed and used to simulate diurnal and semi-diurnal tides in order to plan observation programs. A review paper on the storm surge problem in the Bay of Bengal reached final draft stage. (Contact: T.S. Murty, R.F. Henry.)

**Observing Methods**

Following the development of a general theory of the response characteristics of conductivity cells and its successful application to the Neil Brown
range of cells, an experimental test program was designed for the Guildline Mk IV CTD temperature and conductivity sensors, to elucidate the response characteristics of the sensors over a speed range 0.25 to 1.8 m/sec of fall speed. A preliminary analysis of the results indicates a close agreement between the measured response of the conductivity cell and the predictions of the theory. The temperature sensor response exhibited a significant sensitivity to lowered speed, and a simplified analysis suggests that a significant component of this speed dependence arises from the spatially distributed nature of the sensor design. The remaining speed dependence is thought to be a Reynolds number scaling effect on the heat transfer characteristics of the sensor.

The analysis also suggests that by increasing the length of the temperature sensor, its speed dependence can be more closely matched to that of the conductivity sensor. With the existing designs, a good match between the conductivity and temperature sensors is only achieved at a single lowering speed of about 1.5 m/s. Increasing the length of the temperature sensor would extend the matching condition over a range of lowering speed; an important consideration where ship motion modulates the lowering speed. (Contact: D. Topham.)

The investigation of acoustic techniques for measurement of physical oceanographic processes continued at IOS in several ways, including the activities of a graduate studies group through the University of Victoria (plus one student at the University of British Columbia). Studies focused on three areas of acoustic remote sensing: ambient noise in the ocean and its interpretation in terms of air-sea interaction processes, the use of back-scatter sonar systems to measure various water properties and propagation experiments to determine features of the flow field through its effect on sound travelling through it.

The program of measurement and interpretation of underwater ambient noise has revealed new insights on the mechanisms of generation and absorption of high frequency sound in the ocean. Individual wave-breaking events have been identified and the slower modulation of sound by moving clouds of bubbles has been observed. Theoretical modelling of these processes is aimed at deepening understanding of the processes at and near the air-sea interface which account for the highly variable nature of observed signals. The program has now been extended to the observation of sound caused by precipitation. Rainfall, hail and even snow have distinguishable acoustic spectra which have been identified in a pilot study in Cowichan Lake.
Completed projects included a study of acoustic Doppler techniques and their application to study of internal hydraulic flows over a sill and a back-scatter sonar project involving the study of bubble distributions beneath breaking waves, obtained from the submarine U.S.S. *Dolphin*. The IOS Doppler sonar was also used to study vertical motions in tidal fronts. The simultaneous use of an echo-sounder, Doppler sonar and microstructure shear probe is aimed at resolving the structure of these energetic processes over a range of scales (from dissipation scales up to several tens of metres). Also, a program of observation and theoretical analysis is being carried out to determine the phase structure of sound scattered by biological targets; the results having application to the remote measurement of temperature in the ocean.

*Echo-sounder images of flow over the Observatory Inlet sill at various stages of the ebb tide. The evolution of the internal response (which was also tracked with a Doppler sonar and a towed CTD) is analyzed as a three-layer internal hydraulic flow. In the second image, a transition is occurring between two types of internal response (mode two and mode one) and the hydraulic control has advanced upstream from its usual location at the sill crest. This leads to the peculiar condition of a symmetric, super-critical flow over the crest, which suddenly breaks down and forms a rotor about 80m downstream of the shallowest point.*
In August, an experiment was carried out in Cordova Channel to test the application of acoustic scintillation measurement in the ocean. The acoustic system, consisting of a projector on one side of the channel and two hydrophones on the other, operated successfully over a 600m path. The device exploits the concept of an acoustic shadowgraph, the translation of the resulting image being detected by the hydrophones. Currents derived in this way are in excellent agreement with independent measurements obtained from moored instruments. (Contact: D.M. Farmer.)

Simultaneous measurements of bubbles in a tidal front in Haro Strait, obtained with a downward pointing Doppler sonar (left) and an echo-sounder (right). The Doppler measurements on the left show vertical speed deduced from acoustic backscatter by bubbles and other targets, calculated for various depths as indicated. The echo-sounding image on the right shows plumes of bubbles drawn down by convergence in the front. The bubble plumes attain speeds exceeding 25 cm s$^{-1}$. 

Comparison of current speeds in Cordova Channel derived from a moored recording current meter (continuous line) and from an acoustic scintillation system (horizontal bars). The scintillation measurements were obtained by transmitting an acoustic signal across the channel and receiving at two horizontally separated hydrophones. Turbulent fluctuations in the water mass move with the mean flow; the corresponding motion of the acoustic pattern through the hydrophone array is then used to deduce the current speed.
The major activity of the remote sensing group at IOS in 1984 was the evaluation of the Fluorescence Line Imager, a new type of optical sensor with programmable spectral bands. It was developed for DFO purposes as part of Canada’s space program. The sensor was flown by aircraft over freshwater lakes in June, over the Gulf of Mexico in September and over the Gulf Stream off the U.S. east coast in December. The resulting data are being analyzed at IOS using the image processing system and also by Moniteq Ltd., makers of the instrument. The flexibility of the instrument to form images and to record optical spectra from different targets is clearly demonstrated. The system noise level and calibration are being improved as part of the evaluation work. (Contact: J.F.R. Gower.)

Computing Services

During 1984, the workload on the Institute’s Sperry 1100/60 mainframe computer increased significantly, reaching effective saturation during the prime shift with little idle time over-night. This large increase was due primarily to new scientists on staff engaging heavily in numerical modelling applications.

A long-range study of IOS computing requirements was begun in the spring. This led to a contract with DMR & Associates to assess the situation, examine whether IOS should continue to rely on a mainframe computer for its central computing facility or should utilize distributed super-mini computers with specialized peripherals and to make recommendations. The results of this study are expected in the spring of 1985.

Partly because of the mainframe overload, and partly because of a better fit to specific applications, nearly two dozen personal computers were acquired during 1984. These systems are used for instrumentation control, scientific data analysis of small data sets, word processing and administrative tasks. Thus the trend to distributed processing continues.

Field programs during 1984 continued another trend—the use of more intelligent sensors to gather data at higher rates and in larger volumes. This placed greater strains on all shore-based systems, especially the mini-computers. Plans were made to upgrade mini systems in several
areas to accommodate this increased processing requirement. (Contact: R.E. Johns.)

Ocean Chemistry

The major objective of Ocean Chemistry Division is to provide expertise, advice and a scientific perspective on both short-term and long-term problems associated with the chemical aspects of the oceanic environment through both monitoring and research activities. Five major areas are of prime concern: ocean pollution, ocean climate, ocean flux, ocean circulation and ocean productivity. The main effort is directed toward basic understanding of the long-term consequence of anthropogenic manipulation of the natural environment, but a balance is also struck by studying the short-term environmental impacts of societal intrusion.

Collaborative research is being carried out with international institutes, agencies and universities, including Woods Hole Oceanographic Institution, Scripps Institution of Oceanography, University of Miami, Pacific Marine Environmental Laboratory of NOAA, Shandong College of Oceanology and the Third Oceanographic Institute of the National Bureau of Oceanography in the People’s Republic of China. Regionally, collaborative studies are being carried out with the Department of Oceanography at U.B.C., University of Victoria, Royal Roads Military College, Department of the Environment and the Pacific Geoscience Centre. External funding was received through the Office of Energy R & D and the International Development Research Centre.

Pollution Research

The major effort in 1984 concerned pollution in B.C. fjords with special emphasis on the Alice Arm/Hastings Arm area. A cruise was conducted to collect pore waters of sediments affected by mine tailings from past Amax mine disposals in Alice Arm and from the old Anyox copper mine into Granby Bay. Slag-tailings were dumped 50 years ago into Granby Bay and have been capped by recent natural sediments. A fibreglass catamaran with a plastic enclosure was tested on the cruise for in situ study of effects of tailing-contaminated sediments on the ecosystem and for sea water
chemistry. Lead 210 dating of sediment cores collected in the area and chemical analysis of the metals were completed for a final data report.

Metal-biota interaction was studied in cooperation with Habitat Management Division of DFO by analyzing the heavy metals and metal-binding proteins in Golden King crab (*Lithodes aequispina*) from Alice Arm and Hastings Arm. Sample manipulation was done inside a clean laboratory and protein chemistry was determined by a differential pulse polarographic procedure. Levels of copper in muscle and levels of copper and zinc in hepatopancreas of the crabs were statistically higher, possibly implying the old slag-tailings as a source. Metal-binding protein (MBP) concentrations were found in the hepatopancreas to be unexpectedly high at an average 1.4 percent of the dry-weight. In other areas of southern Vancouver Island, MBPs of the digestive glands of oysters had been correlated with contaminant sources of zinc and copper. (Contact: J.A.J. Thompson.)

Hydrocarbon work involved mainly the interaction of oil droplets, natural particulates, bacteria and phytoplankton by chemical analysis of the samples collected in the 1983 enclosure experiment of Prudhoe Bay crude oil dispersed with Corexit 9527. The finely-dispersed oil droplets generated with self-mixed dispersant rapidly became associated with large organic floc-like structures, possibly generated by bacteria. The oil/floc/bacterial aggregates were sedimented through physical entanglement with sinking diatoms. The straight-chain n-alkanes were removed completely from the oil within several days as indicated by both the quantification by gas chromatograph/mass spectrometer/data system (GC²/MS/DS) and by carbon 14-labelled n-hexadecane added as a tracer.

The GC²/MS/DS was upgraded with a computer-based laboratory information management system (LIMS) to conduct a study of the reliability of capillary column chromatography and the effect of solvent. Preliminary results indicated blind spots for detection by specific detectors insensitive under certain solvent conditions. (Contact: W.J. Cretney.)

Ocean dumping research in 1984 was directed toward providing guidance to obtain quality data and reporting. A highly-interactive, nationwide information exchange on metal analysis in sediments was conducted in cooperation with National Research Council, Environmental Protection Service and Bedford Institute of Oceanography with participating laboratories from government and the private sector. Technical reports were compiled on data interpretation for RODAC (Regional Ocean Dumping Advisory Committee) and on the development of pollution regulations and their application in scientifically-objective ways. Laboratory protocols
of validation of chemical analytical methods in sediment (ruggedness
tests), measuring performance characteristics and storage tests were
introduced into the routine procedures at IOS. (Contact: R. W. Macdonald.)

Trace Metals in Sea Water

Baseline levels of mercury in the waters of Alice Arm and Hastings Arm
were found to be very low. Total, dissolved and particulate forms were
measured using a sensitive technique to pre-concentrate the mercury on
gold beads. The total mercury in both the tailings-contaminated waters
of Alice Arm and the natural background waters of Hastings Arm was
between 2 and 4 ng kg\(^{-1}\) of mercury in sea water on the cruise in August
1983; in line with levels in Saanich Inlet but lower than open-ocean
mercury values of 5 ng kg\(^{-1}\) for the eastern Pacific Ocean studies during
the CSS Hudson cruise in 1981.

A series of laboratory experiments were conducted to quantify the release
of metals from (a) Alice Arm sediment contaminated by mine tailings; (b)
Burrard Inlet sediment with high mercury of 3 ppm and False Creek
dividement of 1 ppm mercury; and, (c) harbour sediment from Xiamen, P.R.
China. A three-month storage study indicated little release of cadmium
at 1 or 10 ppm of sediment in sea water, but a ten-fold increase at 100
ppm in the Alice Arm tailings-sediment study. Lead showed increases of
up to a two-fold change for 1, 10, and 100 ppm of sediment in sea water.
Mercury did not show a marked release in sea water from high mercury
sediments. In the Xiamen harbour sediment study, lead, cadmium, copper,
zinc, nickel, and cobalt were measured. Cadmium, nickel, and zinc
exhibited no change; copper an increased constant level with increasing
sediment/sea water ratio. Lead and cobalt indicated an initial release in
the first 24 hours, then dropped to the same level after several days.

Intercalibration samples collected at Station P in 1981 were analyzed and
compared to aliquots processed and analyzed at the California Institute
of Technology. The soluble lead data obtained by clean laboratory and
mass spectrometric technique both at IOS and Caltech showed good
agreement for levels in open ocean waters of between 2 to 18 ng kg\(^{-1}\).
High lead values were found in sub-surface waters marked by high
nutrients in waters influenced by the California Undercurrent flowing
into the area during the summer. (Contact: C.S. Wong.)
Ocean Flux

Experiments were carried out under two international cooperative programs: Seafluxes and Parflux. The former was funded partially by the International Development Research Centre (IDRC) with a three-year cooperative program involving P.R. China and Canada to conduct marine ecosystem enclosed experiments (MEEE) at Patricia Bay, B.C. and in Xiamen, China. Participating institutes included the Third Oceanographic Institute of the National Bureau of Oceanography as well as the Shandong College of Oceanology both in P.R. China, the Department of Oceanography at U.B.C., and the Ocean Chemistry Division at IOS. The objective is to understand the pollutant dynamics in the marine environment. In the period August 7-24, 1984, 15 scientists and technical staff conducted an enclosure experiment at Patricia Bay on the behaviour and biological effects of mine tailings dredged from Alice Arm. Three large plastic enclosures of 60 m³ were used: one as a control, one with the addition of 2 kg and another with 12 kg in wet weight of tailings to the surface waters. Levels of dissolved, free and particulate metals (copper, cadmium, zinc, and lead) were measured, together with ecosystem parameters of nutrients, productivity, planktonic species and population, particle sizes and distribution. Lead was the only metal found to be released in significant amount from the tailings into the sea water. The major effect appeared to be that of the suspended particulates in sea water, causing a decrease in light transmission. The resulting slower photosynthesis, in turn, lead to a better balance between the organic production by the phytoplankton and the zooplankton grazers, both in phase. This is in contrast to the situation in the control bag, where the uninhibited photosynthetic production was much ahead of the population increase rate of the grazers, thus leading to disequilibrium and rapid detritus fallout. A scientific steering committee consisting of senior scientists of participating institutes from both countries and an IDRC representative met at UBC to review the progress of the joint program and for future planning. (Contact: C.S. Wong.)

The Parflux sediment trap project was carried out as a cooperative venture with Woods Hole Oceanographic Institution. Three cruises, April 16-29, September 3-16 and November 5-25, to Station P (50°N 145°W) and along Line P retrieved and re-launched the automated moored sediment traps at 1000 m and 3800 m. Due to continuous usage for two and one-half years under rugged conditions at sea, a number of mechanical failures and electronic malfunctions led to a loss of a substantial amount of data and samples. However, the flux of material in 1984 appeared to be much lower than in 1983, which may be related to the El Nino year and/or a population
explosion of tunicates in the subarctic waters. In order to establish the production function for flux modelling, primary productivity measurements were carried out on the November cruise using metal-free carbon 14 techniques. Exceedingly high winter values of 200 mg C m\(^{-2}\)d\(^{-1}\) were obtained, compared to the historical data of about 30 mg C m\(^{-2}\)d\(^{-1}\) in the 1950s. \(\text{Contact: C.S. Wong.}\)

**Marine Carbon Research Centre**

The Ocean Science and Surveys' Marine Carbon Research Centre (MCRC) at IOS, now in its sixth year, is focussing on the marine aspects of the global carbon dioxide (CO\(_2\)) cycle by conducting research, monitoring and modelling activities. The Centre took a lead role by conducting the second meeting of the Scientific Committee on Oceanic Research (SCOR) at Lake Arrowhead, California in May 1984. Fifteen participants from P.R. China, Japan, French Noumea, Australia, Germany, France, U.S.A., and Canada reviewed the technical and scientific basis for oceanic CO\(_2\) studies, the global network design and the coordination of observational programs, with particular emphasis on a Pacific monitoring scheme in which our MCRC and the Pacific Marine Environmental Laboratory of NOAA formed the major components. The IOS program in 1984 was supplemented by funds from the Panel of Energy Research and Development to carry out some of the proposed SCOR work such as instrument development and creation of CO\(_2\) standards, but an untimely cut left a few significant programs unfunded in the next fiscal year.

The ship-of-opportunity program was used on both the Canada Ace between Tokyo and Richmond, B.C. and the Lilooet between Brisbane in Australia, Noumea in New Caledonia and Richmond, B.C., to provide time-series data on atmospheric and ocean CO\(_2\), physical oceanography and productivity measurements in the Pacific Ocean for research and modelling. The PERD funds made possible shipboard testing of the automated partial CO\(_2\) measuring system on the Lilooet. Two cruises, in May and in December, 1984 were manned by technical staff from Ocean Chemistry Division to investigate the source/sink relationship of oceanic CO\(_2\) in the surface Pacific Ocean. A seasonal shift of the equatorial oceanic source of CO\(_2\) was observed. A CO\(_2\) standards laboratory was being set up with funds from PERD to measure CO\(_2\) accurately by the state-of-the-art manometric method so that oceanic “snapshots” of CO\(_2\) levels in the open-ocean can be established by repeating sectional measurements once every two to three years. \(\text{Contact: C.S. Wong.}\)
CO₂ research and modelling in 1984 concentrated on two aspects. The first was on setting up a diagnostic model of Canadian atmospheric CO₂ to study the relationship of sources and sinks from the Canadian land forest, Arctic and oceanic CO₂ reservoirs in the context of a global carbon cycle. Part of the work was published in the Journal of Geophysical Research on the trends of atmospheric CO₂ over Canadian WMO background stations at Ocean Station P, Sable Island and Alert. The second was on constructing a "biological pump" model to describe the mechanism of the removal of atmospheric CO₂ by photosynthesis in surface waters and the detritus sinking of both calcareous carbon (shell) and organic carbon (fecal pellets) into deep ocean storage, based on sediment trap data. (Contact: C.S. Wong, Y. Chan.)

A program on the oceanic contribution to background acidity (Acid Rain) was initiated as a cooperative project with Atmospheric Environment Service. Air-sea exchange of freons, a chemical with greenhouse effects, was studied together with oceanic measurements of freons to trace intermediate waters as a joint thesis project with the University of Victoria. (Contact: C.S. Wong.)

Ocean Ecology

Plankton

In 1984 the Institute of Ocean Sciences participated in Project SUPER, an international study of the Subarctic Pacific ecosystem with its major emphasis on the balance between phytoplankton productivity and zooplankton grazing. Unlike most temperate and boreal regions, the Subarctic Pacific shows little or no seasonal cycle in phytoplankton biomass, despite an ample supply of dissolved nutrients and a strong spring and summer peak in primary productivity. The combined effects of high grazing capacity, spatial distribution, and developmental timing of the dominant herbivorous zooplankton have been hypothesized as the major factors limiting the phytoplankton crop. Project SUPER was designed to test the validity of this hypothesis. The Canadian effort included measurements of zooplankton spatial distribution and species composition (Mackas), phytoplankton growth as a function of light intensity (Forbes),
Water column structure and vertical distributions of some dominant herbivorous zooplankton species in the vicinity of Station P (50°N, 145°W) during May 1984. The upper panel shows temperature and salinity profiles. Shaded areas show the range of profiles measured in May 1984; circles and error bars show the mean and standard deviation of May samples 1958-1981. Lower panels show average day and night profiles of Neocalanus plumchrus, Neocalanus cristatus and Eucalanus bungii. Despite the relatively weak physical stratification in the upper 75m, the zooplankton showed strong vertical zonation with little day-night variability.
and vertical exchange of water and organisms within the upper layer (Garrett and Denman). The only strong stratification was associated with the halocline at 70-90 m. Despite the weak stability above this level, a small upper temperature gradient (depth variable between 25 and 50 m) largely prevented deep wind mixing. Much of the vertical exchange appeared to be associated with diurnal convection. Both the phytoplankton and zooplankton showed vertical population differences across the weak upper thermocline. This was particularly strong for the herbivorous zooplankton with Neocalanus plumchrus occurring day and night in the uppermost layer, and Eucalanus bungii and Neocalanus cristatus concentrated between the upper thermocline and the halocline. Most of the herbivorous zooplankton showed little or no diel vertical migration, and grazing potential was highest in the near surface layer where phytoplankton growth was fastest. (Contact: D. Mackas, K. Denman, R. Forbes.)

*Daily cycle of photosynthetic capacity (Pmax) from four 24-hour experiments in B.C. coastal waters. Top Panel: individual measurements of Pmax, each normalized to the maximum value recorded in its experiment. Bottom panel: mean and standard errors of data, divided into 3-hour bins. A sine curve drawn through the data shows the form of the cycle and demonstrates the mid-day depression in Pmax.*
Schematic design for the microprocessor-controlled turbidostat. The culture vessel resides in a temperature-controlled water bath. Small subsamples of culture are pumped through the light sensor via piping circuit A. When the controller receives a signal that the culture is too turbid (and hence too concentrated), a relay is tripped to start pumping culture out through piping circuit C and replacing that with fresh medium through circuit B. Pumping continues until the desired culture concentration is achieved. As the time rate of volume overflow pumped is directly related to the rate of algal primary production in the culture vessel, a time series of the rate of production is obtained for the duration of each experiment.

Results from the SUPER cruise to the northeast Subarctic Pacific reinforced findings that the availability of dissolved nutrients is not the factor limiting primary photosynthetic production by phytoplankton, unlike many other oceanic regions. Rather, light intensity and quality, and their interaction with the cycling of phytoplankton cells by vertical mixing and internal wave motions, appear to control the realized primary production in adjacent coastal and oceanic waters.

For example, in several regions along our coast the maximum rate of photosynthesis at a given light level undergoes a definite daily cycle. To determine whether this cycle is a natural rhythm or whether it results from adaptations to recent light levels experienced by the algal cells, a microprocessor-controlled turbidostat for growing algal cultures under programmable light cycles of different frequencies and intensities was constructed. A turbidostat maintains the cultures at approximately constant cell concentrations by flushing out part of the culture when the light transmission through a small volume of the culture decreases due to an increase in the cell concentration and hence in the turbidity. Initial experiments with the turbidostat have been successful, although for certain species, if the dominant cell size in the culture changes markedly during an experiment, its optical transmission properties may also change. The result is that overall biomass concentration may change even though the optical transmission remains constant. Such effects can be monitored with particle sizing counters and hence can be accounted for in the turbidostat experiments. (Contact: K. Denman, R. Forbes.)
Benthos

Analysis of samples taken in Alice Arm after the cessation of deposition of tailings showed that those areas most seriously affected (nearest the mine) had recovered somewhat. Recolonization of sediments at line C involved polychaete worms, clams and amphipods. The picture was confused by a general reduction in faunal abundance at the less affected sites, but this was matched by a similar reduction in faunal abundance in Hastings Arm. There is an apparent progression from dominance by polychaete worms nearest the mine, and clams furthest from the mine. Samples were not obtained from these deep water stations in 1984, but Amax of Canada Limited sampled the shallower sediments closer to the mine outfall than the area covered by our study of 1983 and 1984. (Contact: R.O. Brinkhurst.)

The study of the benthos of the continental shelf off Vancouver Island progressed this year. Most of the study collection has been sent to various authorities for verification of local identifications, and the results for the major groups are now to hand. Much of the data has been retabulated to simplify the proposed report, with the complex data being archived. As soon as verifications are complete the report can be edited. (Contact: R.O. Brinkhurst.)

The study of squat lobsters (Munida) discussed in earlier reports has now progressed to the point that Fisheries Management is the primary sponsor of a project to see if this abundant, quite large animal can be exploited either directly as a food source or indirectly as food plus colouring material for salmonid aquaculture. At present Munida is a side catch of the prawn fishery that has to be sorted out and rejected. If retained and added to the unused parts of shellfish which are currently wasted, the combination might well provide a valuable by-product. (Contact: R.O. Brinkhurst.)

Samples of the benthos in Boundary Bay, B.C. were taken in a joint study with the Environmental Protection Service. Some question about the possible lasting effects of a toxic waste spill into Highland Creek and a tenuous connection to the death of grey whales in Puget Sound provided the initial stimulus for this project which fits into the Environmental Protection Service continuing analysis of disturbed and undisturbed local habitats. (Contact: D.F. Moore.)

Taxonomic studies of estuarine oligochaetes continued with a detailed review of the genus Tubificoides world-wide. Many sets of specimens were identified for outside agencies. A reconstruction of the evolution of the
Naidid family of oligochaetes, from a hypothetical ancestor to the species found today, is being carried out. The process of inferring the path of evolution has two stages. The first stage includes the careful examination and identification of specimens, determination of a set of characters that provide a precise description of all species, and the assessment of the characters for each extant species and the hypothetical ancestor. The information is then coded and analyzed using computerized mathematical methods for determining the most plausible phylogenetic tree, with the hypothetical ancestor at the root and the extant species at the tips of the branches. Phylogenetic trees give us insight into the process of evolution and provide a logical framework for the classification of living organisms. (Contact: A. Nemec.)

Time Series Analysis

Observations of oceanographic variables, such as temperature and velocity dissipation, are found to deviate considerably from the usual assumption of a log normal distribution. This can lead to serious miscalculation of quantities of interest if a log normal distribution is used. Consequently, alternate representations are being sought. A contaminated Gaussian model and a nonlinear, non-Gaussian autoregressive model are being developed. (Contact: A. Nemec.)

The analysis of oceanographic time or spatial series frequently involves a search for periodicities. Standard spectral analysis and fitting of trigonometric functions requires that the observations be equally spaced with respect to time or space. This is not always possible. Methods for searching for periodicities in arbitrarily spaced observations are being investigated. (Contact: A. Nemec.)

The Division participated in two cruises, in June and August 1984, involving the discovery and sampling of hydrothermal vent fields in Explorer Ridge at 50°N, 130°W. Two specific problems were investigated:

The alvinellid polychaete Paralvinella palmiformis was selected for an exploratory study of metals and metalloids at hydrothermal vents. Results to date reveal that P. palmiformis accumulates elemental sulfur in a mucus layer on its epidermis. Shed mucus traps significant quantities of sulfide minerals, and may be important in the formation of mineral deposits at some vent sites.

Bacterial biomass in exiting vent fluid was related to fluid physiochemical properties. In addition to Explorer Ridge vents, samples were obtained
from a University of Washington cruise to Endeavour Ridge vents. Results suggest that conditions most favorable to sub-seafloor bacterial growth are created when the ascending hydrothermal fluid mixes extensively with intruding seawater. Future work will involve an expanded study of the coupling of physical, geochemical and microbiological processes below the seafloor in hydrothermal circulation cells. (Contact: S.K. Juniper.)

A large bacterial mat (100-500 Ha) in the lower reaches of Saanich Inlet was identified as primarily a monoculture of sulfide-oxidating bacteria. *Pisces IV* was used to study the influence of deep water renewal processes on the growth and distribution of these organisms. The mat was found to be remarkably dynamic in its ability to respond to fluctuating oxygen conditions and colonize the new habitat as made available by deep water renewal. (Contact: S.K. Juniper.)

### Ocean Information

Ocean Information activities support the management, protection and exploitation of marine resources. Primary responsibilities include the collection and dissemination of oceanographic research data, the conduct of marine climatological analyses, the evaluation of environmental reviews, and the provision of information and advice through various committees to regulatory agencies. The Division also oversees the regional ocean dumping research program, provides information to OSS clients, media and the general public, and provides policy and planning support for regional operations.

### B.C. Shorestation Oceanographic Program

During 1984, the B.C. Shorestation Oceanographic Program (lighthouse, monitoring program) provided surface-seawater salinity and/or temperature data from 18 locations. Preliminary examination of these data indicates that the large positive anomalies— with respect to the long-term mean—that characterized the “open ocean” stations in the first half of 1983 did not occur in 1984. Conditions at these stations (such as Amphitrite Point and Langara Island) have returned to near the “normal” state.
A considerable portion of the 1984 data was provided to agencies such as the International Pacific Salmon Fisheries Commission and the Pacific Biological Station as well as to private firms and individuals. The data from 1982 and 1983 were published in 1984. All the data obtained since the formal initiation of the program in the mid-1980's is now archived at IOS; programs for the processing and for the determination of some first-order statistics for these data at IOS were prepared during 1984 and are now in place. Preliminary work associated with the proposed updating of the 1972 report summarizing all data obtained since the program’s inception is underway. (Contact: L.F. Giovando.)

Ocean Advisory Services

In 1984, IOS continued to provide considerable support to the Regional Ocean Dumping Advisory Committee (RODAC) and the Arctic Waters Advisory Committee (AWAC) by reviewing environmental terms and conditions for Arctic offshore exploration and Pacific coast dredging and dumping proposals. The Division also managed extensive R & D contractual work ranging from the quality evaluation of methodologies for marine sample analysis to ocean process studies pertaining to the release of heavy metals from dredge spoils. The annual Ocean Dumping Workshop which dealt with these and other topics, such as ocean sediment transport, was hosted by the Institute in December.

Division staff also contributed significant effort to numerous environmental assessment and marine planning committees and to interdepartmental initiatives. In particular, the Arctic Offshore Development Committee (ARCOD) was tasked with technical review and DFO position statements for Panarctic’s Bent Horn oil production project, CMO’s Lancaster Sound exploration plan and, the most demanding, Dome/Esso/Gulf EIS (Environmental Impact Statement) on Beaufort Sea hydrocarbon production and transportation. Based to a large degree on the scientific and technical evaluations of the Institute’s researchers and hydrographers, the department’s position on Beaufort development included the following overall recommendations: development should occur at a rate commensurate with the demonstration of safety, reliability and environmental acceptability; only demonstrated projects for subsea pipelines, offshore production facilities and year-round marine transportation of hydrocarbons may proceed at this time; and, expansion of offshore production and transportation should be considered only after the demonstration projects are shown to be safe, reliable and environmentally acceptable. These and other recommendations were heeded by the Beaufort Environmental Assessment Review Panel.
Several interdepartmental marine policy evaluations were attempted with the assistance of the Division related to such matters as abandonment of artificial islands and designation of Arctic waste dump sites.

The West Coast Offshore Development Committee (WESCOD) carried out detailed technical scrutiny of the Chevron and PetroCanada proposals for exploratory drilling in Hecate and Queen Charlotte Straits and other B.C. coastal waters. The industry documents were considered useful tools for identifying the major environmental issues. However, the restricted scope and the apparent scarce or unavailable oceanographic data necessitated a formal request of the proponents, through the West Coast Assessment Panel, for additional re-assessment and future research commitments.

In related matters, ARCOD prepared the Department of Fisheries and Oceans' brief to the Special Senate Committee on the Northern Pipeline for its Offshore Transportation Study. *(Contact: L.F. Giovando, B.D. Smiley.)*

**Ocean Data Services**

Ocean Information Division’s Data Compilation and Appraisal Program for the Arctic and Pacific coast published the seventh volume of a series of data inventories; this one pertaining to the currents, water levels, temperature and salinity measurements obtained in the Canada Basin and Arctic Ocean. Approximately 340 data sets (1883 to 1983) were compiled and described, resulting in a catalogue of station location maps, tabular summaries of time and location of all measurements, the actual parameters measured and the type of instrumentation, etc. The measurements were appraised or evaluated according to their collection methods and materials, storage and analysis. Unfortunately, necessary documentation was not forthcoming for the majority of the studies, even after considerable pursuit.

The design and implementation of the Oceanographic Data Information System (ODIS) continued as a Division priority, with the goal of providing rapid search and sort of multi-disciplinary ocean data set information using interactive computer graphics. Data inventories dealing with the physical, chemical and biological oceanography of Arctic and Pacific waters were formatted for inclusion in ODIS with the intention of providing off-site access to users by 1986.

Technical Records section acquired an additional 800 documents, bringing total holdings to approximately 2500, related to assessment, regulation and management of offshore waters (Arctic and Pacific coast). The bulk
The locations of all temperature-salinity profile data collected off the Alaskan coast in the months of September and October, excluding data obtained by Soviet investigators and U.S. oil companies for which locations are not available.

of these documents are considered as "grey literature", i.e., not scientifically refereed or published in recognized journals. Nevertheless, such information is useful in resolution of many issues regarding marine safety and environmental protection. (Contact: B.D. Smiley.)

Public Information

The fourth in a new series of IOS Annual Reviews was completed along with contributions to various departmental and inter-departmental annual reports.

A public display covering IOS activities was featured in the federal government pavilion at the Pacific National Exhibition and some elements were subsequently installed on-site at IOS.

The number of visitors to IOS continued to grow in 1984 making thrice-weekly tours now standard practice.
Media liaison was provided for special events such as the launching of the C.S.S. John P. Tully and Pisces IV dives and for on-going programs. (Contact: K. Glover.)
SHIPS
Launch day at Bel-Aire Shipyard in North Vancouver; October 27, 1984.
The Pacific Region Ship Division provided ship, submersible, launch and depot support for the 1984 scientific and hydrographic programs of the Institute of Ocean Sciences, other federal agencies and universities.

Of note in 1984 was the construction of the William J. Stewart replacement vessel. The contract was awarded to Bel Aire Shipyard Ltd. The keel was laid on January 30, 1984, and the launching took place on schedule on October 27, 1984. Named John P. Tully after the man known as “The Father of West Coast Oceanography”, the vessel continues the trend to multipurpose ships, fulfilling both hydrographic and oceanographic functions.

The steel hulled, 69 metre John P. Tully will cruise at 12 knots with a range of 12,000 nautical miles and can accommodate 15 hydrographers or scientific personnel and a ships complement of 25. The ship is equipped with four 8.8 metre aluminum survey launches and a comprehensive navigation system that includes Sat Nav, Loran C, Omega and a doppler log in addition to radars and gyros. It is expected that the ship will be fully operational for the 1985 season.

C.S.S. PARIZEAU (64.3 m overall; 1929 tonnes)
Master: A.G. Chamberlain   Chief Engineer: G. Winterburn

The Parizeau provided support for Ocean Physics, Tidal and Current Surveys, Ocean Chemistry, Department of National Defence, P.G.C., the University of British Columbia and the University of Washington. A large part of the summer was devoted to Hecate Strait surveys for Hydrographic Division. Parizeau also saw service as a primary Search and Rescue vessel during the herring roe season.

C.S.S. VECTOR (39.6 m overall; 505 tonnes)

The Vector provided support for Ocean Physics, Tidal and Current Surveys, Ocean Chemistry, EPS, P.G.C., University of British Columbia and Royal Roads Military College.
C.S.S. RICHARDSON (19.8 m overall; 78 tonnes)
Master: J. LeGarff  Acting Master: M. Wheeler

The Richardson was tasked as a primary SAR vessel during the herring roe season and was used in support of field survey parties by Hydrographic Division.

M.V. PANDORA II; on charter (58.2 m overall; 1220 tonnes)
Master: S. Gulati  Chief Engineer: R. Rogers/H. Doherty

The Pandora II provided support for Ocean Physics, EPS, Bamfield Marine Station, Pacific Biological Station (PBS), B.C. Provincial Museum and the University of Victoria, UBC and Simon Fraser. The majority of these programs were in conjunction with the submersible Pisces IV.

PISCES IV (6.1 m overall; 12 tonnes)
Chief Pilot: F. Chambers

Operating mainly from the charter vessel M.V. Pandora II, the Pisces IV made over 120 dives in support of Ocean Ecology, Ocean Physics, EPS, Bamfield Marine Station, PBS, B.C. Provincial Museum and various university programs. While working at the northern Explorer Ridge much new scientific information was gathered.

Barge PENDER

In addition to acting as mothership for the Pisces IV, the Pender was extensively used in field support for the Hydrographic Division. Surveys took place in Smith Inlet, Fish Egg Inlet and the Hardwicke Island area.

Institute Workshops

Normal repair and upkeep of the Institute’s fleet of over 30 launches and small boats was continued throughout the year as was support to the Parizeau, Vector and Richardson. Mechanics were provided for both the Pender and Parizeau during their periods of hydrographic service. A new 7 metre tender for the submersible Pisces IV was constructed in the shops as well as a second rigid inflatable. Painting, fitting out and preparation for Canada Steamship Inspection of the 8.8 metre aluminum launches intended for the new ship is ongoing. Six of this class of launch are now in service. Both generators on the barge Pender have now been converted to a marine cooling system.
Deck Machinery

An on-going service program for winches and support equipment required for the various scientific cruises was maintained. In addition, major rebuilds of nine winches were undertaken. Some limited assistance to the Champlain Centre in Quebec was also provided.
MANAGEMENT SERVICES
Management Services

For Management Services Division, 1984 was a mixed year. In some areas the Division was able to accomplish tasks that had been outstanding for a long time, in others, lack of progress was evident and frustrating.

In the former, the Division administered an employment stimulation program for youth. At its peak this created an additional 86 jobs all directly associated with Institute programs. The large majority of these jobs were science related; however significant improvements to building and grounds were made through the FRED program.

Exploiting the advances in office technology and integrated systems continued to have a high priority in the planning process for the Division. Improvements in level of service and in internal productivity coupled to better control are the basic objectives for new systems. Progress in this area in 1984 was somewhat disappointing. This year the Institute relied on the departmental central financial system discarding its 10 year old internal system. For most line managers this proved to be a less satisfactory arrangement. Improved departmental systems are being planned which hold promise but which do not provide immediate relief.

A further example of a significant improvement was the installation of an uninterruptable power supply to the Sperry mainframe computer. This system has been put to the test frequently since it started functioning and has proved reliable.

Being essentially a service division, the normal functions of the Division continued at an acceptable level despite a cut in resources (people and dollars) for the fiscal year 1984/85.
Department of Environment
The upper figure shows the observed changes in the average temperatures over the upper 60 and 160m of the ocean at Station Papa during the Storm Transfer and Response Experiment. The change in the depth of the mixed layer is also shown. The rapid variations are due to sampling biases introduced by internal waves; only the mean curve is significant. The lower figure shows the estimated cooling due to the computed cooling at the surface, due to evaporation and sensible and radiative heat losses. For the period November 14 to about December 5, the observed cooling exceeded the calculated cooling due to surface heat loss; for the remaining period they are about equal.
Atmospheric Environment Service

Atmosphere-Ocean Interactions

In order to model the global climate, it is necessary to understand the role of the oceans in the transfer of heat from the equator to the poles. Past studies of the North Pacific Ocean have led to contradictory results: some indicating a poleward heat transfer; others an equatorward transfer. Two different approaches to estimating the oceanic transfer are being pursued. The exchanges with the atmosphere lead to an estimation of the oceanic heat transport as a residual. Unfortunately, the best estimate of the uncertainties in the computations of the atmospheric-oceanic heat fluxes are such that the possible errors exceed the residual. Hence, although the data do indicate an equatorward heat transfer in the North Pacific Ocean, much confidence cannot be placed in the result. The data do show large differences from year-to-year, which are significant. These interannual variations are being further investigated.

An alternate approach is to investigate oceanographic measurements to deduce the oceanic transport more directly. Two sections across 35°N have been examined. They both show a transfer of heat toward the equator. The mean gyre circulation contributes very little to this transport because the depth-averaged temperature of the northward flowing water is almost the same as the southward flowing water. The principal transport is due to a meridional overturning with warmer water moving southward (relative to the gyre). Although both sections give southward heat transfer, the values for the two years are quite different. The effects of different sampling strategies are being investigated.

The upper ocean is particularly sensitive to direct atmospheric forcing; i.e., heat and momentum exchanges. During the Storm Transfer and Response Experiment (STREX), measurements of ocean and atmospheric parameters were made regularly and it is possible to monitor the atmospheric forcings and the oceanic response. It was found that for a period of two weeks, the ocean cooled more than the amount of heat lost at the surface to the atmosphere. This was a particularly stormy period, and the best estimates of oceanic advection (due to wind-induced currents) indicate that they are important to the balance. For the following period of 10 days, the oceanic cooling was approximately equal to the estimated
heat loss to the atmosphere. Thus, it appears that simple one-dimensional mixed layer models are inadequate to model the upper-ocean cooling during periods of strong winds. (Contact: G.A. McBean.)
Research on seabirds continued in 1984 with studies on two gull species being initiated.

The first study was on the foraging of Bonaparte’s Gulls in areas of upwelling and along fronts and tidal eddies in Active Pass. This is the first of a series of investigations planned to determine the significance of upwelling and density fronts as feeding habitats for seabirds on the British Columbia coast.

Bonaparte’s Gulls visit Active Pass from late August to late November on their migration south from their breeding lakes in northern British Columbia, the Yukon and the Northwest Territories. The gulls visit Active Pass again from March until the end of May on their return to their northern breeding grounds from the U.S. west coast. At Active Pass, the gulls feed on euphausiids and amphipods. In areas without upwelling, the gulls’ diet consists mostly of fishes. The gulls feed offshore by shallow plunge-diving or by dipping for and seizing their prey from the surface of the water.
The objectives of this study are to determine 1) why thousands of Bonaparte’s Gulls feed at Active Pass (apparently related to the abundance of zooplankton prey); 2) why feeding is restricted to the fall and spring; and 3) what time of the year euphausiids and amphipods are most available to the gulls in Active Pass. To attempt to obtain answers to those questions 1) gulls are collected each month that they are present in Active Pass in order to determine their diet; 2) zooplankton is sampled each month of the year (whether gulls are present or not) in both upwelling and control areas (east and west entrances to Active Pass); and 3) temperature and salinity profiles by a Beckman conductive salinometer and visibility by Secchi disk are determined at the sampling stations.

The second study involved the Mew Gull, which nests solitarily either on the ground of small islands or in trees along the shores of oligotrophic coastal lakes in British Columbia. The nesting habitat of Mew Gulls is being studied to determine 1) which lakes the gulls prefer for nesting purposes; 2) why the gulls select certain nesting sites on islands and not others; 3) their diet during their breeding cycle; and 4) their reaction to predators (large gulls and eagles). Answers to the above questions may provide insight as to why Mew Gulls nest solitarily—atypical nesting behaviour for gulls.

A report on the distribution and populations of pelagic seabirds in Hecate Strait and Queen Charlotte Sound was completed in December 1984. Surveys of seabirds in Dixon Entrance and on the west coast of Vancouver and Queen Charlotte Islands were initiated in October 1984. These surveys will continue until late 1985; the results will provide preliminary information about seabird distribution and populations on the British Columbia Shelf. (Contact: K. Vermeer.)
The Pacific Geoscience Centre (PGC) continued to expand and improve its efforts in a broad range of marine and land-based geoscience disciplines over the past year. Staff and budget have increased and 50 people now work at PGC. With the additional resources have come increased responsibilities, notably the Offshore Boundaries Geoscience Program and the Frontier Geoscience Program. These programs have specific and relatively short term objectives, but they have also led to some very exciting fundamental scientific studies. The Boundaries Program continues until 1986. It is focussed on acquiring the data base and resource appraisal for the Shelf and Juan de Fuca Ridge which will be required for future offshore boundary negotiations.

The Frontier Geoscience Program will continue until 1990, at which time it will be reviewed and possibly renewed. The PGC component is directed primarily at the sedimentary basins that may have petroleum potential along the western margin of Canada and in the northern Yukon-Beaufort Sea region. Particular attention is being paid to Queen Charlotte Sound, Hecate Strait and the adjacent land areas. Renewed interest in petroleum exploration in the area has generated a need for additional geoscience data to support resource appraisal and the evaluation of potential hazards to development—such as earthquakes and sea-floor stability.

Juan de Fuca Ridge studies continued to be an important part of the PGC effort, with organization of, or involvement in, a number of cruises and submersible dive programs during the year. The SEABEAM swath bathymetric mapping in co-operation with NOAA (U.S. National Oceanographic and Atmospheric Administration) and the SeaMARC acoustic imaging surveys in co-operation with the University of Hawaii, the Lamont Geological Observatory, and the U.S. Geological Survey, have now provided seafloor maps and images of the ridge, equivalent to the topographic maps and aerial photographs available on land. Particularly exciting have been the discovery and initial mapping (with several university groups) of deposits of sulphide minerals associated with hydrothermal vents.
Along the margin, a major effort was made by PGC and a number of other government and university organizations in the Lithoprobe Program, an integrated geoscience study of deep crustal structure. The first phase, a traverse across Vancouver Island, was a notable success. The Vibroseis seismic reflection data clearly show the Juan de Fuca oceanic plate dipping at a shallow angle beneath the Island. Integrated with a wide variety of geological and geophysical studies, the seismic data have permitted a remarkably detailed picture of the deep structure and geological processes occurring along the western Canada convergent margin.

Of special significance to PGC and to marine geoscience in Canada in general, was the recent decision that Canada would become a member of the international Ocean Drilling Project (ODP). This project will lead, both to deep sea boreholes adjacent to Canada that will make critical contributions to our understanding of the Canadian offshore, and to the involvement of Canadian scientists in the forefront of marine geoscience around the world.

I have outlined above only a few of the many outstanding geoscientific studies that the staff of the Pacific Geoscience Centre have undertaken during the past year, and of which they can be justifiably proud. It has been an exciting and productive year. (R.D. Hyndman.)

Sedimentology

Estuarine and Marine Delta Sedimentation

As in previous years demand remained high for geological data from the Fraser River Delta to help formulate environmental/engineering guidelines. The results of geological research have been applied to investigations by outside agencies relating to: the proposed Iona Island sewage pipeline; Westshore Terminals coal port expansion, the proposed B.C. Hydro Vancouver Island gas pipeline and design of a breakwater for the Tsawwassen Indian Reserve.

One highlight of the summer's field activities was the completion of an assessment of mechanisms influencing tidal creek erosion of ecologically
valuable eelgrass beds. The study area was adjacent to the Roberts Bank Coal Port on the Fraser River Delta. The work was performed in association with students from the Engineering (Geological) Department of U.B.C. The other highlight was the completion of the first phase of a coring program in the Fraser River Delta to decipher its structure, lithology and paleoenvironments. The work was performed by personnel of the Geography Department of Simon Fraser University in conjunction with PGC.

(Contact: J.L. Luternauer.)

Continental Shelf Sedimentation

Research continued on the mapping of geological hazards to hydrocarbon exploration and production in Queen Charlotte Sound. This year’s studies included employing side-scan sonar, Huntex Deep-Tow high resolution seismic profiling and piston coring. The data reveal major sand wave and boulder fields and suggest the presence of an extensive late Pleistocene debris flow. The debris flow could have been triggered by the collapse of

![Lithographic description of Core 8 (asterisk) from Queen Charlotte Sound. The debris flow deposit consisting of a poorly-sorted, shelly, gravelly and sandy mud is identified by the spike in the sand concentration approximately 2.5m into core. This unit is recognized in other cores from the immediate region and on Hunter Deep-Tow records between coring sites. It overlies glacial deposits and is buried by post-glacial sediments probably derived from adjacent fjords. This debris flow deposit, which extends for over 50km (area enclosed by saw-toothed line), was probably generated by submarine slope failure (at or near the site of the arrow) sometime after 12,000 years ago.](image-url)
oversteepened side walls from a shelf ice-stream valley, by entrainment of older material in meltwater/tidal current torrents as glacial ice sheets retreated across the shelf, or by seismically triggered failure of older deposits on either Goose Island Bank or Sea Otter Shoals. The records also suggest that no major recent faulting or failure has occurred within the surveyed areas. (Contact: J. Luternauer.)

Modern sedimentation in Georgia Strait is dominated by the input from the Fraser River. Its submarine delta deposits extend nearly to the Gulf Islands. The Foreslope Hills, located midway between Sand Heads and Galiano Island, are a broad series of parallel ridges and troughs in the delta muds. They comprise a major slump structure (10 km N-S by 6 km E-W by more than 150 m thick). Detailed surveys made 15 years apart have been compared to assess changes in the seafloor morphology of this disturbed region.

The sediment ridges have remained fixed in position and depth. However, the low lying troughs between the ridges and the regional foreslope above and below the ridges show vertical sediment accumulations ranging from one metre on the eastern (upslope) side to several metres on the western (downslope) side. There is also a pronounced increase in sediment
thickness at the downslope edge from +4 m in the north to +13 m in the south, implying a southerly sediment input, possibly from Roberts Swell. These bathymetric changes suggest high sedimentation rates of 0.07 to 0.8 m/yr. At these rates, the relief on the ridges will become subdued in a few tens of years, emphasizing the youthfulness of the seafloor instability of this region. (Contact: T.S. Hamilton, PGC; G. Eaton, CHS.)

A research project on the early diagenesis of shelf sediments, and specifically the formation of glauconitic smectite, was carried out on samples from the Vancouver Island shelf with Pierre Giresse of the University of Perpignan, France. It was found that these iron- and potassium-rich, green, sand-sized grains can develop within a few thousand years in areas of low sedimentation on the outer continental shelf. Recent formation of these minerals is more prevalent off British Columbia than on other continental margins because of the more readily available iron in unstable detrital minerals.

Typical glauconitic sand grain from Vancouver Island continental shelf.

Scanning electron micrograph of glauconitic smectite growing in voids in a sediment aggregate from the continental shelf west of Vancouver Island.

A survey of the nearshore geology and morphology of Virago Sound, northern Graham Island, was carried out in October/November using echosounding, side scan sonar and grab sampling. (Contact: B.D. Bornhold.)
Fjord Studies

A highly successful cruise was undertaken to Bute Inlet with participants from Louisiana State and Texas A&M universities. The aims of the study were to map the slope failure morphology in the upper part of the fjord, to obtain cores for geotechnical analyses and to interpret the history of, and processes involved in, submarine landsliding in the Inlet. It appears that massive failures of the fjord-head delta have taken place during the Holocene which have resulted in channel formation and deposition of sandy lobes in the deeper parts of the Inlet. Subsequent aperiodic events have transported sandy sediments through these channels and on to the basin floor up to 25 km from their source at the head of the fjord. Bute Inlet will be the site of a multiyear program involving further side-scan sonar mapping, shallow seismic profiling, coring, bottom-mounted current meters, sediment traps and transmissometer profiles in an effort to better understand the processes involved in such channelized sediment flows. (Contact: B.D. Bornhold.)

Offshore Studies

The study of sedimentation near the Dellwood Knolls continued, in cooperation with Bertrand Blaise and Henri Maillot of the University of Lille, France. It included x-ray diffraction, geochemical and textural analyses, scanning electron microscopy, radiometric dating and oxygen isotope determinations. The significant results to date indicate: very little geochemical influence on sedimentation by the nearby spreading axis; a somewhat greater abundance of smectite relative to other clay minerals in and near the spreading axis than outside it; the cessation of turbidite sedimentation in Dellwood Valley and Dellwood Basin, probably about 10,000 years ago, with the initiation of the Scott Channel system; small (0.2°C) thermal anomalies in the near-bottom waters in central Dellwood Basin; and, significant recent uplift of the Dellwood Knolls and their composite volcanic/sedimentary nature as shown by cores from the top of Southeast Knoll containing sandy terrigenous turbidites and ice-rafted debris. (Contact: B.D. Bornhold.)

Sedimentology Laboratory/Data Section

The sedimentology laboratory provides technical and analytical support for the Marine Geology Subdivision. Primary activities include: field collection of surficial sediment samples and data from offshore, fjords, continental shelf, estuaries and beaches; lithologic descriptions of samples; analysis of samples (approx. 1000 per annum) and archiving of
raw and processed samples.

The Data Section maintains an inventory of both field and analytical data which can be referenced by sample type, location, and analyses. The total number of samples on file exceeds 8500. Plots and print-outs of data and sample locations can be generated. Requests for data/plots/subsamples are filled for researchers within the department and outside, within Canada as well as internationally.

The current thrust for the laboratory is to move to micro-computer acquisition, storage, retrieval and manipulation of data directly from laboratory equipment and to transfer the existing data files from the Univac mainframe to a micro-computer in the lab. (Contact: T. Forbes.)

Bedrock Geological Studies

Lithoprobe – Southern Vancouver Island

Lithoprobe is a collaborative project involving an integrated program of geophysical, geological and geochemical studies designed to elucidate the nature of, and processes within, the lithosphere of Canada. The project is spearheaded by the Vibroseis technique which permits deep seismic sounding, to depths of as much as sixteen seconds (two-way time, Ca 50 Km). The program is funded jointly by the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Department of Energy, Mines and Resources, and involves university, government and industry geoscientists in all phases from initial planning to final interpretation.

The reflection seismic program on Vancouver Island was conducted during late May and June of 1984. Supporting geological and geophysical studies were carried out by scientists of the Pacific Geoscience Centre and by several university geoscientists.

Initial results clearly show that the oceanic Juan de Fuca plate underlies rocks of the continental margin and descends easterly from a depth of about 24 km near the coast to 31 km beneath central Vancouver Island.
Train of reflection seismic vibrators on Vancouver Island.

Preliminary interpretation of southern Vancouver Island transect from reflector geometry and surface geology.
The overlying rocks include two accreted crustal sections, the lower of possible pre-Late Miocene age and the upper of probable Eocene age. Between these two sections, a layered sequence appears to have acted as a zone of detachment for easterly dipping thrust faults that extend into the upper crust and project to mapped faults and intrusive contacts at the surface.

The dominant structural style of Vancouver Island that is emerging is one of east-west shortening by a combination of thrust faulting and folding of crustal and upper mantle rocks. The fault displacements decrease in age generally downwards and westwards. (Contact: C.J. Yorath, A. Sutherland-Brown, M.T. Brandon, N.W.D. Massey.)

**Queen Charlotte Islands**

The lavas of the Cenozoic Masset Formation are being studied as part of an ongoing program by the Geological Survey of Canada to investigate the volcanic rocks of the Insular Belt and the adjacent deep ocean. The Masset Formation is of particular interest because of its hydrocarbon shows and its dominant role in the Tertiary Stratigraphy of the Queen Charlotte Islands and adjacent parts of Hecate Strait and Queen Charlotte Sound. Understanding the origin and genesis of these lavas will provide constraints on the tectonic evolution of this part of the Continental margin.

**Queen Charlotte Islands**

Symbols:
- B, basalt;
- BA, basaltic andesite;
- A, andesite;
- D, dacite;
- R, rhyolite;
- TA, trachyandesite.

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*ALKALI-SILICA DIAGRAM (dry wt.%) FOR MASSET VOLCANICS*
Activities in Palaeontology and Biostratigraphy in 1984 centred around studies of the Jurassic foraminifers and stratigraphy of the Queen Charlotte Islands. Several new stratigraphic units have been recognized, some of which have significance as primary hydrocarbon source beds, so others may prove to be good stratigraphic hydrocarbon traps in subsurface.

The Jurassic of the Queen Charlotte Islands spans approximately 40 million years of earth history in the interval 206 to 166 million years ago. The rocks are composed of a complex sequence of mixed volcanic and sedimentary rocks which nevertheless carry rich fauna of both macro and microfossils. It is currently estimated there are about 400 species of foraminifers throughout this section, which while providing an excellent means of dating the rocks, indicate the environments in which the rocks were deposited. The sizes of the illustrated microfossils vary from 0.5 to 1.5 mm in length. (Contact: B.E.B. Cameron, M. Johns.)

Nodosaria opalini Brand Frondicularia bicostata bicostata d’Orbigny Lenticulina d’orbignyi (Roemer)
Juan de Fuca Ridge Mapping

Detailed SEABEAM mapping efforts were continued in a cooperative effort with S. Hammond of NOAA on the production of several new 1:50,000, 10 m contour map sheets and 1:250,000 regional compilations over the northern Juan de Fuca Ridge system. The maps have already been put to use both for direct tectonic interpretation and as base maps for geophysical studies using lowered, deep-towed, and bottom-deployed instruments, and using the research submersibles Alvin and Pisces IV. (Contact: E. Davis, R. Currie, B. Sawyer.)

Mapping of seafloor features is also continuing at a finer scale, using the deep-towed SeaMARC I acoustic imaging system in cooperation with W. Ryan, Lamont Doherty Geological Observatory. Images produced by this system are much like aerial photographs on land, and features of sizes down to a few metres can be resolved. Extensive surveys carried out over the northern Juan de Fuca Ridge and Explorer Ridge have yielded many surprising results.

Citharina flabellata (Gümbel)
Extensive lava flows are common on the seafloor near the ridge crest. Sources of these flows are both at the ridge crest itself and on the flanks of young seamounts. Some flows extend 20 to 30 km. The shape and surface morphology of the flows are strikingly similar to those of subaerial basalt flows.

A great number of hydrothermal features are also observed, many of which are along normal fault scarps, others of which are situated over well sedimented unfaulted crust. Some of the constructions have substantial relief (50 m) and extent (300 m) and have been found to be currently active (see Marine Studies). (Contact: E. Davis, N. Massey, B. Sawyer.)

Seismological Service

The Seismological Service provides earth scientists, civil engineers, resource development industries and the public with basic earthquake data and with research information concerning natural and induced earthquakes, ground motion seismic risk, earth structure, and nuclear explosions. This is accomplished through a network of seismological stations, including standard and regional stations, two telemetered arrays, strong motion accelerographs and special installations.

Seismic Networks

The Western Canada Telemetered Network (WCTN), established to provide centralized, on-line monitoring of seismicity in southwestern British Columbia, was expanded in 1984 by one station in Strathcona Park. Eighteen stations are now being recorded at the Pacific Geoscience Centre, including three stations of the University of British Columbia network. One regional station has been added to the Queen Charlotte area network at Langara Island. (Contact: D.H. Weichert, G.C. Rogers, R.B. Horner and M. Bone.)

The strong motion seismograph network in western Canada consists of instruments designed to operate and record ground acceleration only when very strong earth motion occurs (1/2% of normal gravity or larger). During 1984, one new instrument was added in the Queen Charlotte area for a total of 36 accelerographs. A review of the growth and current status of
the Canadian strong motion program was made for the International Association of Seismology and Physics of the Earth’s Interior. The Miramichi earthquake series of 1982 has given a significant impetus to the development of the Canadian strong motion instrumentation program. The accelerograph network of the National Research Council is now under the direction of Earth Physics Branch and extra funding has become available for upgrading the western network.

**Special Earthquake Studies**

The Beaufort Sea special seismicity study continued through the better part of the year. Dome Petroleum withdrew from the cooperative project and the four Beaufort Sea shore stations were closed in July. When alternate funding became available in the fall, stations at Komukak Beach, Shingle Point and Nichelson Point were reopened. These are telemetred to the standard seismograph station at Inuvik.

An isoseismal map of the 1949 magnitude 8.1 Queen Charlotte Islands earthquake was completed. The data are sparse, but clearly show this event to be much larger than the 1906 San Francisco earthquake. *(Contact: G.C. Rogers.)*

An investigation of the microearthquakes recorded on the Queen Charlotte Islands since the first seismograph was installed in 1970 showed very little activity east of the Queen Charlotte Fault, although last year’s field experiment clearly did record some activity in that region. *(Contact: G.C. Rogers.)*

**Western Canada Seismicity**

The Pacific Geoscience Centre is responsible for locating all earthquakes recorded in western Canada for inclusion in the national earthquake data file. Data from 51 stations are now processed, and some 750 earthquakes were located during the year. During 1984, 18 earthquakes were reported felt in western Canada. These included one on southern Vancouver Island, one on the Queen Charlotte Islands, five in southern British Columbia, four in northern British Columbia, four in southwestern Alberta, and three in Saskatchewan. No earthquakes were reported felt in the Yukon Territory. The largest earthquake to occur in western Canada during the year, magnitude 5.8 on June 24, was centred south of the Queen Charlotte Islands. The earthquake on the Alberta-British Columbia border on February 11, magnitude 4.7, was the most widely felt. No damage was reported in western Canada for any earthquake in 1984. *(Contact: R.B. Horner, G.C. Rogers, D.H. Weichert.)*
Seismic Risks

PGC continues to supply site specific seismic risk calculations based either on the extreme value method of Gumbel, as specified in past versions of the National Building Code of Canada, or alternatively, requests can be made for the new method that will be introduced in the 1985 edition of the National Building Code. (Contact D.H. Weichert.)

Gravity

The principal mandate of the Gravity Service is to establish the shape of the geoid in Canada to the highest standards and to determine the value of gravity on a regional basis over the Canadian landmass and offshore areas. The regional gravity data provide information for both the determination of crustal structure and the evaluation of resources and are critical to the operation of inertial navigation systems.

The focus of regional land gravity surveys was shifted this year to the Yukon Territory where approximately 450 new gravity stations were established along a 100 km wide corridor centred on the Dempster Highway between Dawson City (64°N) and Fort McPherson (67°N). In addition, regional gravity profiles were established across the Eagle Plain Basin between the Dempster Highway and the settlement of Old Crow and in the Northwest Territories along the abandoned Canol Road from Norman Wells to MacMillan Pass.

Detailed gravity transects of about 1 km spacing were conducted across the Tintina Fault in the vicinity of Ross River and near Dawson City. The detailed coverage at both sites will provide a better understanding of the fault geometry in the upper crust.

A detailed transect was also made across the seismically active Richardson Mountains at about 67°N. Preliminary results show a Bouguer anomaly high of 35-50 mGal present along the spine of the mountain range indicating the likely absence of an underlying crustal root.

Approximately 85 gravity stations were visited along a detailed transect
of Vancouver Island between Dunsmuir and Pachena Bay as part of project LITHOPROBE.

Due to the cancellation of the resource charting cruise, there was no offshore gravity program in 1984. (Contact: J. Sweeney, D. Seemann.)

**Thermal Studies**

The earth’s temperature influences both rock properties and geological processes. Thermal data, particularly surface heat flux, are important indicators of deep tectonic processes and the structure of the earth’s crust. Most active tectonic processes that result in mountain building, earthquakes and volcanism, originate from thermal energy. Geothermal data also are needed to calculate the degree of maturation of hydrocarbons. In addition, the earth has considerable economic potential as a heat source for geothermal energy.

Measured thermal parameters include surface heat flux (the result of vertical temperature gradient multiplied by the thermal conductivity of the rocks) and heat production from natural radioactive decay in crustal rocks (for example: thorium, uranium and potassium). Studies cover a wide range of geological and geophysical interests – from heat flow, heat production and thermal processes in the deep sea floor to the discovery and development of geothermal energy resources in western Canada.

**Land Studies**

Geothermal data were acquired along the LITHOPROBE profile on Vancouver Island as well as in holes drilled for mineral exploration in areas near Clearwater, Banks Island and Anyox. Samples for heat generation measurements were collected from intrusive bodies in southeastern B.C. Gamma-ray spectroscopy measurements on cores near the shelf indicate that depositional age estimates depend on the half-life of 226Ra rather than 230Th. H. Villinger is testing a pulsed needle technique in the laboratory for rapid measurements of the thermal conductivity of chip samples.
A manuscript on heat flux in southwestern B.C. shows that the Intermontane and Omenica Crystalline Belts form a single heat flow province with a high heat flow, similar to areas of the Basin and Range province to the south. Low heat flux under the Insular Belt and Coast Plutonic Complex is the result of subduction. An abrupt change in heat flux over a distance of 20 km along Jervis Inlet is thought to reflect a thermal boundary above the zone where the hot asthenosphere flowing at first toward and then down with, the subducted oceanic crust and entrapped sediments, starts to significantly heat the subducted material. A data file containing all the results of heat generation measurements up to 1984 was published. (Contact: T. Lewis, W. Bentkowski.)

**Marine Studies**

The collection, analysis, and interpretation of heat flow data from the Jurassic sea floor of the Western Pacific are well under way as part of a continuing study of the thermal history of old oceanic lithosphere with workers from University of Texas and University of Washington. The heat flow is generally higher than that which can be explained by any simple cooling history. A widespread reheating event may be the cause of the anomalously high heat flow. (Contact: E. Davis, H. Villinger.)

Heat flow studies have been conducted over a well sedimented axial valley of the northern Juan de Fuca Ridge. A number of active hydrothermal features have been identified and basement (hence probably groundwater) temperatures beneath the sediment fill have been established to be in excess of 300°C. (Contact: E. Davis, H. Villinger.)

**Geomagnetism**

**The Geomagnetic Field**

The earth's geomagnetic field varies both spatially and temporally. This inherent variability is exploited in a variety of ways. To be utilized for navigation, the magnetic field and its gradual change with time must be determined as a function of latitude and longitude. Spatial changes in the magnetic properties of rocks also lead to spatial variations in the magnetic field which can be used as signatures of structure, composition and the thermal history of crustal rocks. Short-period temporal changes in the
magnetic field are measured to resolve subtle field variations as encountered in exploration geophysics.

In Canada, the geomagnetic field is monitored continuously at 13 primary observatory sites. As part of this Canadian Geomagnetic Network, PGC operates the Victoria Geomagnetic Observatory on property at the Dominion Astrophysical Observatory. (Contact: L. Law, D. Auld.)

**Geomagnetic Variations**

Temporal variations in the earth's magnetic field provide a source of electromagnetic energy with which to probe the earth's electrical conductivity structure. Electrical conductivity is an important parameter in understanding the active tectonic regions on the west coast. Deep zones of high conductivity, related to high temperatures and partial melting, determine the maximum thickness of the cold lithosphere riding over the asthenosphere. Conductive zones at shallow depths occur in regions with geothermal resource potential.

A magnetotelluric survey across central Vancouver Island, along the northern two Lithoprobe lines, obtained data at eighteen sites with the Phoenix geophysics system. The survey provided important new information about the electrical conductivity structure of this subduction region.

An innovative method has been developed, in cooperation with the University of Toronto, to determine the electrical conductivity of the seafloor. The Magnetometric Off-Shore Electrical Sounding method (MOSES) utilizes a source field produced by an electric current transmitted by a long wire, extending from the sea surface to sea floor, and measured by an ocean-bottom magnetometer. Using this method, the resistivity and thickness of the sedimentary section beneath Bute Inlet was determined to be 1.9 ohm-metres and 560 metres respectively. The MOSES method was also used over two areas near the Juan de Fuca Ridge, at the central and southern end of Middle Valley, at a depth of 2200 metres. Analysis of the data from the central area gave a resistivity of about 0.8 ohm-metres and a thickness of approximately 1800 metres for the sediments. At the southern end of Middle Valley the sediment cover was only 200 metres. The underlying fractured basalt layer, with a resistance of 9 ohm-metres, extends to a thickness of over 1000 metres in this area.

A controlled source sounding of a young basalt flow in the axial valley of the Juan de Fuca Ridge was carried out using the United States deep submersible Alvin to position the seafloor instrumentation.
The monitoring of changes in apparent resistivity related to the increase in tectonic strain in central Vancouver Island continued at two sites in the area. To date, there has been no significant change observed in the resistivity data over the four-year duration of the experiment. (Contact: L. Law, J. DeLaurier, D. Auld, D. Nobes.)

**Paleomagnetism**

The paleomagnetism of rocks records the variations in directions of the geomagnetic field in the geological past. The intensity of the ancient field is also recorded, but is difficult to observe and can only be obtained in very favourable circumstances. The principal application of paleomagnetism is in tectonics—the study of the motion of continents, the opening and closing of oceans and the origin of mountain belts—but it is also used widely in many problems of stratigraphic correlation, the origins and thermal history of rocks and in the source and origin of magnetic anomalies.

Paleomagnetic work at PGC is concerned with the tectonics of the Cordillera and the western Arctic and with magnetostratigraphic studies. During the last decade, geological and geophysical studies have shown that the Cordillera comprises a number of distinct crustal blocks. Vancouver Island is part of one such block. Paleomagnetic work has shown that these blocks have been transported from the south by distances over 1000 km; much of central British Columbia once being in the latitude of California or further south. Indeed, Vancouver Island could have moved northward by over 5000 km relative to North America and may have originated on the other side of the Pacific Ocean. The western Cordillera, therefore, appears to be a collage of small crustal fragments that originated elsewhere, were carried over large distances, and finally were glued to North America. This discovery has led to a profound revision of ideas about the origin of this and other mountain belts.

Two major programs are underway. The objective of the first is to collect a suite of rocks along a traverse across the Cordillera from Vancouver Island to the Rockies in order to determine the relative latitudes of the various crustal elements at one geological instant in time; namely the Middle Cretaceous epoch near 100 Ma ago. The second program calls for a traverse across the northern rim of the Sverdrup Basin at Ellesmere Island.

Further collections of Cretaceous and Permian rocks were made in Axel Heiberg in 1984 in collaboration with the Institute of Sedimentary and Petroleum Geology (ISPG), and of Cretaceous and Tertiary rocks in
collaboration with Geological Survey of Canada, Vancouver. Notable results are from a Cretaceous intrusion near Prince Rupert (Smith Island gabbro) which yields a multiplicity of reversed and normal magnetizations commonly present in the same specimen. Work by a student from Carleton University yields a secondary magnetization of probable mid-Cretaceous age in Triassic rocks of the Quesnel Terrane. All those Cordilleran mid-Cretaceous data indicate a displacement of the western Cordillera by 2000 km to the south at that time. (Contact: E. Irving, P.J. Wynne.)

Geodynamics

The principal subject of study for Geodynamics in the active region of the west coast of Canada continues to be contemporary crustal deformation. One main objective of this is to establish realistic dynamic models of crustal plate behavior at plate margins and utilize these in the study of local earthquakes.

Currently, three geodetic measurement techniques are being applied in the area of central Vancouver Island in order to monitor ongoing crustal deformation: precise gravity, vertical control and horizontal control surveys.

Semi-annual surveys of the central Vancouver Island precise gravity network, which were initiated in 1977, were again completed during 1984. Most of the observed gravity changes to date can be related to changes in water levels of the Strathcona Reservoir or changes in local groundwater levels. The past year has also seen significant improvements in the gravity data handling capability at PGC. Input to the national database in Ottawa and network analysis of any contained data can now be carried out directly from the west coast.

Precise elevation measurements were made by the Geodetic Survey of Canada along Highway 19 between Parksville and Kelsey Bay. Portions of this route had been levelled before in 1930, 1946 and 1977-78. Raw instrumental heights suggest a continued relative uplift to the north by about 3 or 4 cm between 1977 and 1984; however, these data could still be subject to systematic error.

Trilateration measurements were also carried out by the Geodetic Survey
on the central east coast of Vancouver Island. This survey work repeated earlier triangulation measurements in the area of Johnstone Strait [1918, 1966] and Forbidden Plateau [1978]. The 1984 data are currently being reduced and analyzed and they may prove critical in resolving temporal and spatial variations in crustal strain in this active region.

As part of the NASA Crustal Dynamics Project, the first occupations of the Whitehorse and Penticton VLBI [Very Long Baseline Interferometry] sites by the NASA mobile radio antenna were completed in August 1984. These represent the first in a series of annual measurements planned over the next five years to monitor changes of the order of a few centimetres in baselines measuring thousands of kilometres. The Penticton site is being used in conjunction with the Yellowknife, N.W.T. and Algonquin, Ont. sites to monitor crustal deformation of the North American craton. The Whitehorse site serves as a reference location in the study of plate deformation in Alaska. The initial deployment of the mobile antenna at the remote sites of the Alaska campaign was carried out using a Hercules aircraft and thus presented a number of challenging logistics problems. *(Contact: H. Dragert.)*
Technical Support

Two technical services groups provide electronic and mechanical engineering support for the Pacific Geoscience Centre. The principal responsibility is the operation and maintenance of scientific and support equipment. Of increasing importance is the upgrading of existing equipment and the acquisition, preparation, maintenance and operation of new equipment.

A major advance in deep water capability was realized in 1984 with the purchase of a deep-tow winch with 8,000 metres of armoured co-axial cable. During the summer of 1984 this winch was used to carry out a wide swath, deep-tow side-scan survey of the offshore ridge system within Canada's 200 nautical mile economic zone. It is expected that any experiments which require power delivered to depth and/or data recorded on board in real time will make use of this system. This presents considerable opportunities to advance capabilities for high resolution side-scan surveys, real-time sea floor video, still photography of large areas and even perhaps the deployment of a deep water remotely operated vehicle. (Contact: R. Macdonald.)

The use of mini- and micro-computers to control experiments and to log and process data is an area of extensive effort. Two IBM-PCs have been installed in the paleomagnetics laboratory to reduce Univac on-line time. In the sedimentology laboratory an IBM-PC is being installed to automate and integrate the sedigraph and settling table techniques. Sediment sorting and distribution parameters will be calculated once the whole sample size distribution has been derived. Cruise data acquisition and logging will now be carried out using an IBM-PC with GPIB interface. This will replace PHAS, a portable digital data acquisition system. At present, the new system accepts navigational, bathymetric and magnetic data. Development of a multi-channel digital seismic system based on a P.D.P. computer was continued. (Contact: W. Hill, I. Frydecky, G. Horel.)

An upgrading of side-scan sonar capabilities was realized with the purchase of K-MAPS. This system records survey parameters, corrects the data for scale changes due to variations in ship speed and then prints the data from a vertical rather than oblique perspective. Most ships in the research fleet (Parizeau, Vector, Endeavour) have been refitted to accept deep coring and long heat probe (11 metre) equipment. (Contact: W. Hill, R.D. Macdonald.)
An additional solar-powered seismic telemetry station was installed at Mt. Septimus on southern Vancouver Island.

Offshore there was participation in a four-week cruise on CNAV Endeavour in June/July in support of the SeaMARC II mapping survey; seabed sediment heat flow measurements with a telemetering heat probe; and ocean-bottom geomagnetic measurements of both the earth’s magnetic field and of generated fields, utilizing five successful deployments and recoveries of ocean bottom magnetometers. Technical support was also provided on a one-week cruise out of Seattle aboard the University of Oregon’s Research Vessel Wecoma to deploy and recover the University of Toronto-designed MOSES system (ocean bottom transmitter and receiver) along the Endeavour segment of the Juan de Fuca Ridge. The deployment of the ocean bottom system from the support ship Atlantis II was followed by variation of the transmitter/receiver spacing via movement of the receiver package on the seafloor by the submersible Alvin.

Seafloor conductivity measurements were continued on two separate cruises to Bute and Toba Inlets, in conjunction with the University of Toronto, utilizing MOSES.

Initial planning and requisitions were completed for the addition of a VAX 11/750 to perform expanded data analysis on the seismic data acquired by the WCTN. Several additional IBM-PC micro-computers were also acquired. One of these was utilized for shipboard preliminary reduction, analysis and plotting of data from the telemetering heat probe. Preliminary efforts are underway to utilize an IBM-PC controller and analyzer for making shipboard measurements of thermal conductivity of core samples. (Contact: M.N. Bone, H.J. Bennetts, H.A. Whitford.)

Areas that are going to receive particular attention in the future are deep water photography, seismic (both deep penetration and shallow penetration-high resolution) and wire rope maintenance. (Contact: I. Frydecky, R. Macdonald.)

**Boundary Studies**

Between 1984 and 1987 PGC will generate a complete bibliographic
geoscience data base for the western Canada offshore international boundary areas in cooperation with the Atlantic Geoscience Centre, ISPG, Polar Continental Shelf Project and Earth Sciences, EMR, Ottawa and through a series of contracts and in-house studies. To date emphasis has been on regional data. In 1985 the focus will shift to detailed studies, resource appraisals plus data compilation and presentation as required by the Department of External Affairs for offshore boundary negotiations. The final output will be catalogues, data files and information summaries covering the boundary areas at Juan de Fuca, Dixon Entrance and the Beaufort Sea. (Contact: J.B. Boyd.)
APPENDIX I

Contracts Awarded 1984

A. Department of Fisheries and Oceans

Develop a Computer Programming Training Course for IOS Personnel
Anthony Macauley Associates, Victoria, B.C. ....................... $ 7,475

Develop Software on IOS Image Processing System
Apocalypse Enterprises, North Saanich, B.C. .......... 19,000

Engineering Design of a Remote Liquid Crystal Display for Field Hydrography
Applied Microsystems Ltd., Sidney, B.C. .... 3,211

Develop a Conductivity, Salinity, Temperature, Depth and Water Velocity (CSTDV) System
Applied Microsystems Ltd., Sidney, B.C. ........... 25,452

Develop and Construct a Microsystem Format Magnetic Tape Translator
Applied Microsystems Ltd., Sidney, B.C. ........ 11,780

Compilation of Existing Chemical Oceanographic Data Sets for the Canadian West Coast Offshore Waters, Straits of Georgia and Juan de Fuca, Canada Basin and Arctic Ocean
Arctic Laboratories Ltd., Sidney, B.C. .... 19,445

Compilation of N.W. Passage Zoobenthos Data
Arctic Laboratories Ltd., Sidney, B.C. ........ 48,049

Compilation and Appraisal of Existing Chemical Oceanographic Data from Queen Charlotte Sound, Hecate Strait and Dixon Entrance
Arctic Laboratories Ltd., Sidney, B.C. .... 25,982

Prepare and Test Acoustic Equipment and Recording Systems for the OERD Project to Determine Acoustic Scattering Parameters in Arctic Waters
Arctic Sciences Ltd., Sidney, B.C. .......... 12,998

Compilation and Appraisal of Report for Physical Oceanography Data in Queen Charlotte Sound, Hecate Strait and Dixon Entrance
Arctic Sciences Ltd., Sidney, B.C. .............. 34,565

Acoustic Scattering Measurements in Arctic Waters
Arctic Sciences Ltd., Sidney, B.C. ........... 48,559

Development of a Digital Signal Processing Capability for the Extraction of Sea Ice Movement Data from Hard Copy Remote Sensing Imagery
Arctic Sciences Ltd., Sidney, B.C. ........... 108,923

Acoustic Measurements of Flows in Channels
Arctic Sciences Ltd., Sidney, B.C. ........... 81,008

Analysis of Active Sonar Schemes for Measuring Wind Direction
Arctic Sciences Ltd., Sidney, B.C. ........... 33,439

Compilation and Appraisal of Existing Physical Oceanographic Data in the Canadian Basin of the Arctic Ocean
Arctic Sciences Ltd., Sidney, B.C. ........... 18,020

Analysis of Arctic Acoustic Backscatter Data
Arctic Sciences Ltd., Sidney, B.C. ........... 30,187

Investigate the Feasibility of Employed Gas Discharge Tube Technology for the Removal of Biofouling Rust, Paint, etc.
Associated Sheet Metal Products Ltd., Victoria, B.C. .......... 28,570

Evaluation of Radiosonde Observations to Determine Optimum Methods of Computing Geostrophic Winds in Parry Channel
Atmospheric Dynamics Corp., Victoria, B.C. .... 12,535

Enhancements to Hydrographic Contouring Software Package
Barrodale Computing Services Ltd., Victoria, B.C. .......... 15,687

Investigation of Stereo-sidescan Sonar Imagery
Barrodale Computing Services Ltd., Victoria, B.C. .......... 36,000
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<tr>
<td>Provide Services of a Programmer/Analyst</td>
<td>Barrodale Computing Services Ltd.</td>
<td>Victoria, B.C.</td>
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<td>Ship of Opportunity Sampling of the Planktonic Ecosystem off the Pacific Coast of Canada</td>
<td>Broccoli Bros. Enterprises Inc., Sidney, B.C.</td>
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<td>Analysis of Marine Zooplankton Samples</td>
<td>Broccoli Bros. Enterprises Inc., Sidney, B.C.</td>
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<td>Evaluate an Ice Pressure Sensor, Inclusion Factor on Vertical Stress Distribution</td>
<td>Canada Marine Engineering Ltd., Calgary, Alberta</td>
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<td>Development of an Electrical Power Generator to Derive Useful Energy from Salinity Gradients through Application of Reserve Electro-dialysis Techniques</td>
<td>Capital Applied Research &amp; Technology Ltd., Victoria, B.C.</td>
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<td>Multi-disciplinary Geophysical and Hydrographic Survey off Yukon Coast</td>
<td>Cansite Surveys Ltd., Calgary, Alberta</td>
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<td>Develop and Test a Structural Photo-voltaic Model for Marine and Survey Applications</td>
<td>Cantech Scientific Instruments Ltd., North Saanich, B.C.</td>
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<td>Study the Effects of Wood Waste for Ocean Disposal on Recruitment of Marine Benthic Communities (Macro Benthos)</td>
<td>Coastline Environmental Services, Vancouver, B.C.</td>
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<td>Study of Beam Characteristics and Sensitivity of Hydrophones and Transducers</td>
<td>G. Crawford, Victoria, B.C.</td>
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<td>Organisation of West Coast Ocean Dumping Workshop and Preparation of Workshop Proceedings for Publication</td>
<td>Dobrocksy Seatech Ltd., North Saanich, B.C.</td>
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<td>Preparation of Report on Shelf Benthos Project</td>
<td>Dobrocksy Seatech Ltd., North Saanich, B.C.</td>
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<td>Mobilisation of Sea Data System for Development in the North Pacific</td>
<td>Dobrocksy Seatech Ltd., North Saanich, B.C.</td>
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<td>Develop, Construct and Field-test Loran C Tracked Drogues (Cont.)</td>
<td>Dobrocksy Seatech Ltd., North Saanich, B.C.</td>
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<td>Organisation of Workshop on Metal Binding Proteins Produced by Non-Mammalian Organisms in Aquatic Environments</td>
<td>Dobrocksy Seatech Ltd., North Saanich, B.C.</td>
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<td>Develop and Test a Deep Ocean Interstitial Water Sampling Device</td>
<td>Dobrocksy Seatech Ltd., North Saanich, B.C.</td>
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<td>Identify and Enumerate Marine Phytoplankton from Station P</td>
<td>E.V.S. Consultants Ltd., Sidney, B.C.</td>
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<td>Compile, Review and Assess Major Environmental Assessment Reports and Atlases for West Coast of British Columbia</td>
<td>Environmental Services Ltd., Vancouver, B.C.</td>
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<td>A Fibre Optic Implementation of a Remote Sensing Head to Measure In-situ Phytoplankton Fluorescence</td>
<td>Focal Marine, Halifax, Nova Scotia</td>
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<td>Collection and Compilation of Oceanographic Data in the Campbell River Estuary</td>
<td>A. Hartley, Vancouver, B.C.</td>
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<td>Documentation of Specific Oceanographic Data Relating to Various Arctic and Pacific Coastal Areas</td>
<td>R. Herlinveaux, North Saanich, B.C.</td>
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<td>Test and Analyse Echometer Instrument</td>
<td>D. Huston, Victoria, B.C.</td>
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<td>Reduction of STEDPO to One Sounder</td>
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<td>Processing of Current Meter Data Obtained During Stage II of the North Coast Oceanic Dynamics Experiment</td>
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Investigation of a Novel Approach to the Problem of Double Diffusive Instability
Interact Computing Services Ltd., Sidney, B.C. ........................ 153,117

Preparation of Microfiche Tape for Technical Support in Line P Deep Ocean Time Series Analysis
Interact Computing Services Ltd., Sidney, B.C. . 8,528

Develop Additional Range Bearing Functions to HAL/HALPRO Software
Interact Computing Services Ltd., Sidney, B.C. . 7,452

Study of North Pacific Transient and Stationary Heat Fluxes
Interact Computing Services Ltd., Sidney, B.C. ........................ 3,787

Measurements of Hydrographic Launch Dynamics
Interact Computing Services Ltd., Sidney, B.C. ........................ 19,968

Software Package
Interfax Systems Inc., Burnaby, B.C. ............. 15,274

Design of Free Floating Multi-sediment Trip Array
Iseki, Saanichton, B.C. ..................... 22,520

Collection and Analysis of Samples from Moored Sediment Trap and Surface Water Samples in the Pacific
ISK, Saanichton, B.C. ..................... 16,165

Preliminary Study to Determine Various Aspects of Undersea Acoustic Techniques to Determine Rainfall
Jasco Research Ltd., North Saanich, B.C. .... 1,250

Development of an Undersea Acoustic Technique to Determine Rainfall
Jasco Research Ltd., North Saanich, B.C. .... 162,600

Design and Development of an Oceanographic Mooring System off the West Coast of Queen Charlotte Islands
T. Juhasz, Victoria, B.C. ...................... 68,300

Study of Growth Decay of Crystals in Seawater
D.G. Knigge-Sieberg, Victoria, B.C. .... 15,960

Compilation of Tsunami Records
M. Lane, Victoria, B.C. ...................... 621

Study of Antenna Configurations for the Active Drifter
Meteor Communications [Canada] Corp., Victoria, B.C. ............. 1,909

Technical Modification, Maintenance and Test Flight of the Fluorescence Line Imager (FLI)
Moniteq, Concord, Ontario ................... 27,802

Continuation of Technical Improvements and Evaluation of FLI
Moniteq, Concord, Ontario ................. 82,147

Survey of Acoustic Profiling of an Arctic Ice Keel
Offshore Survey and Navigation Ltd., North Vancouver, B.C. .......... 31,640

Develop a Microcomputer-based Tidal Current Display System
Pacific Ocean Sciences Ltd., Burnaby, B.C. ...... 84,000

Study of Numerical Prediction of Wind Generated Waves in the Coastal Area between Queen Charlotte Islands and the Mainland of British Columbia
Pacific Ocean Sciences Ltd., Burnaby, B.C. ........ 124,000

Survey of Practical Data Analysis Techniques used in Physical Oceanography
Pacific Ocean Sciences Ltd., Burnaby, B.C. .... 6,000

Graphical Presentation and Analysis of Oceanographic Data
Pacific Ocean Sciences Ltd., Burnaby, B.C. .... 9,285

Data Interception of Ships of Opportunity
Pacific Ocean Sciences Ltd., Burnaby, B.C. ........ 1,100

Analysis of Marine Tissue Digests by Inductively Coupled Plasma Spectrometry
Quanta Trace Labs Inc., Burnaby, B.C. ........ 3,519

Study of a Marine Boundary Layer Structure and Heat Exchange
S & B Research Ltd., Saanichton, B.C. ........ 6,933

Design for a Thruster for the Active Drifter
Seaboy Marine Services Ltd., Sidney, B.C. ...... 5,000

Study to Develop a Search and Rescue (SAR) Procedure for Hazardous Waters
Seacconsult Marine Research Ltd., Vancouver, B.C. ................. 160,000

Demonstration of SEA-I Research Sidescan Sonar and Manta Underwater Vehicle
SEA-I Research Ltd., Sidney, B.C. ........ 2,500

Organisation of West Coast Ocean Dumping Workshop and Preparation of Workshop Proceedings for Publication
SEA-I Research Ltd., Sidney, B.C. ........ 4,990
Development of a Novel Model Using the Edible Mussel as a Sentinel Organism for Monitoring Organic Contamination of the Marine Environment
Seakem Oceanography Ltd., Sidney, B.C. ............ 7,000

Investigation of a Novel Laser Diode Pressure Sensor
Seakem Oceanography Ltd., Sidney, B.C. .......... 238,000

Analysis of Marine Air Samples from Land Station & Ocean Cruises
Seakem Oceanography Ltd., Sidney, B.C. .......... 40,000

Study of Natural and Petroleum Exploration-related Fluxes of Metals, Hydrocarbons and Nutrients in Queen Charlotte Sound
Seakem Oceanography Ltd., Sidney, B.C. ........... 9,483

Analysis of Dissolved Nutrients in Seawater and Artificial Seawater
Seakem Oceanography Ltd., Sidney, B.C. ........... 6,200

Analysis of Seawater and Sediment Trap Samples for Dissolved Nutrients
Seakem Oceanography Ltd., Sidney, B.C. ........... 6,000

Compilation of Summary Statistics from West Coast Ship of Opportunity Data
Seakem Oceanography Ltd., Sidney, B.C. .......... 9,848

Feasibility Study for the Development of a Fast Response Fibre Optic Dissolved Oxygen Sensor
Seastar Instruments Ltd., Sidney, B.C. ............... 11,677

Determination of Modifications Required for High Frequency Operation of IOS Upward-looking Sonar Array
SH Scientific Computing Ltd., Vancouver, B.C. .......... 4,495

Modifications & Additions to Turbidostat Hardware and Software
SH Scientific Computing Ltd., Vancouver, B.C. .......... 1,650

Development of CADD based Technology for the Production of Maps of Ocean Bathymetry
H.A. Simons International Ltd., Vancouver, B.C. .......... 81,000

Library Cataloguing of Tsunami
P. Straub, Sidney, B.C. ................. 605

Mobilisation of Equipment/Technical Support of Ocean Turbulence Measurements
Sytech Research Ltd., Sidney, B.C. ............... 3,960

Short Circuit Protection for HAL Power Supplies
Sytech Research Ltd., Sidney, B.C. .......... 2,650

Oceanographic Observations Aboard CSS Parizeau
I. Szabo, North Saanich, B.C. ............... 2,550

Develop and Supply a Portable Field System for the Digital Analysis, Correction and Display of Photogrammetric Detail for Hydrographic Field Parties
Terra Surveys Ltd., Sidney, B.C. .......... 58,239

Preparation of Planning Chart of Beaufort Sea
Terra Surveys Ltd., Sidney, B.C. ........... 14,406

Co-ordination of Three Consecutive International Tsunami Meetings for Canada by IOS
Tide and Tsunami Services, Salt Spring Island, B.C. ............... 52,520

Ice Imagery of the Beaufort Sea Nominally South of 75° and its Application to Ice Arching in Restricted Channels
Univ. of British Columbia, Dept. of Oceanography, Vancouver, B.C. .......... 27,216

Study of Tidally Forced Flow Over Sill in Observatory Inlet Using Acoustic and Other Data
Univ. of Victoria, Dept. of Physics, Victoria, B.C. .......... 2,000

Study Comparison of Freon Techniques in Sea Water
Univ. of Victoria, Dept. of Chemistry, Victoria, B.C. .......... 8,455

Measurement of Response Functions of the Temperature and Conductivity Sensors of the Guildline Model 8705 CTD Probe
Univ. of Washington, Dept. of Applied Physics, Seattle, U.S.A. .......... 7,184

Collection and Analysis of Polar Deep Sea Pressure Data
Univ. of Washington, Polar Science Centre, Applied Physics Laboratory, Seattle, U.S.A. .......... 11,880

Preparation of Report on CO2 Data Calibration
Western Ecological Service (B.C.) Ltd., North Saanich, B.C. .......... 16,180
Development of Data, Software and Documentation for Launch Computed Line Following System
Western Subsea Technology, Sidney, B.C. .... 10,375

New Charting Scheming of Mackenzie River, N.W.T.
R. Wills, Victoria, B.C. ................. 20,450

B. Department of Energy, Mines and Resources

Data Compilation and Laboratory Analysis of Sediments for Investigation of Geohazards to Development on the Continental Shelf off Western Canada
K. Conway, Victoria, B.C. ............... 25,448

Marine Survey of Nearshore Sedimentation and Recent Tectonics of Virago Sound, Northern Graham Island
Offshore Survey and Positioning Services Ltd., Vancouver, B.C. .............. 35,000

Development and Testing of a Deep Ocean Interstitial Water Sampling Device
Dobrocky Seatech Ltd., North Saanich, B.C. .... 119,204

Collection of Oceanographic Data using Huntec Deetrow Seismic System
Huntec (70) Ltd., Vancouver, B.C. .......... 23,996

Compilation of Western Canadian Telemetered Network Seismogram Collection
R. Kolinsky, Sidney, B.C. ............... 12,000

Compilation of Western Canadian Telemetered Network Seismogram Collection
P. Wilkman, Victoria, B.C. ............. 12,600

Investigation and Installation of Seismic Station in Queen Charlotte Island Areas
B. Chandra & Associates Ltd., Vancouver, B.C. ............. 5,000

Seismographic Data Collection at Selected Sites on the West Coast of British Columbia
Univ. of British Columbia, Vancouver, B.C. ...... 10,450

Study of Upper Crustal Structure below Hecate Strait from Airguns Ocean Bottom Seismograph Data
Univ. of British Columbia, Vancouver, B.C. ...... 14,727

Study of Crustal Structure of Queen Charlotte Islands—Hecate Strait Region—from Seismic Refraction Studies
Univ. of British Columbia, Vancouver, B.C. .... 14,493

Analysis of Micro-earthquake Data from the Queen Charlotte Islands and Hecate Strait Region
Univ. of British Columbia, Vancouver, B.C. .... 15,000

Investigation of the Earthquakes West of Vancouver Island
Univ. of British Columbia, Vancouver, B.C. .... 20,243

Seismic Monitoring of the Anahim Volcanic Belt in Eastern British Columbia
B. Chandra & Associates Ltd., Vancouver, B.C. ............. 56,000

Preparation of Tailored Bibliographics in the Juan de Fuca International Boundary Area
Envirocon Ltd., Vancouver, B.C. ............. 15,000

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# APPENDIX II

## Publications

### A. Department of Fisheries and Oceans

#### (1) Canadian Data Report of Hydrography and Ocean Sciences

<table>
<thead>
<tr>
<th>No.</th>
<th>Volume</th>
<th>Author(s)</th>
<th>Title</th>
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<tr>
<td>23</td>
<td>1, 2, 3</td>
<td>Thomson, R.E., W.R. Crawford and W.S. Huggett</td>
<td>Water property observations off the west coast of Vancouver Island during CODE: May 1979 to September 1980</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>Giovando, L.F.</td>
<td>Observations of seawater temperature and salinity of British Columbia shore stations, 1982</td>
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#### (2) Canadian Technical Report of Hydrography and Ocean Sciences

<table>
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<th>No.</th>
<th>Author(s)</th>
<th>Title</th>
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<tr>
<td>33</td>
<td>Macdonald, R.W. and H. Nelson</td>
<td>A laboratory performance check for the determination of metals (Hg, Zn, Cd, Cu, Pb) in reference marine sediments</td>
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<td>34</td>
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<td>The selection of tidal boundary condition for a numerical river model</td>
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<td>Brinkhurst, R.O. R.O. Kathman, R.E. Woods and S.F. Cross</td>
<td>Benthic studies in Alice Arm, B.C. following cessation of mine tailings disposal</td>
</tr>
<tr>
<td>44</td>
<td>Brinkhurst, R.O. and M.J. Wetzel</td>
<td>Aquatic oligochaeta of the world: supplement — a catalogue of new freshwater species, descriptions and revisions</td>
</tr>
<tr>
<td>52</td>
<td>Vermeer, K. and L. Rankin</td>
<td>Pelagic seabird populations in Hecate Strait and Queen Charlotte Sound: comparison with the west coast of the Queen Charlotte Islands</td>
</tr>
</tbody>
</table>
(3) Canadian Contract Report of Hydrography and Ocean Sciences

No. 17  S.M. Woods [ed.]  Report on Ocean Dumping ReD Pacific Region, Department of Fisheries and Ocean, 1982-83

No. 15  Fissel, D.B., D.N. Knight and J.R. Birch  An oceanographic survey of the Canadian Arctic archipelago March 1982

No. 16  Fissel, D.B., D.D. Lemon and D.N. Knight  An oceanographic survey of the Canadian Arctic archipelago March 1983

(4) Other Publications


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**B. Department of Environment**


C. Department of Energy, Mines and Resources


RIDIHOUGH, R.P. and D.A. SEEMANN. 1984. Juan de Fuca Plate Map JFP8, gravity anomaly, 1:2,000,000. EPB, EMR.


APPENDIX III

Permanent Staff 1984
Institute of Ocean Sciences

A. Department of Fisheries and Oceans

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Mann, C.R.; B.Sc., M.Sc. (N.Z.), Ph.D. (Brit. Col.),
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Stucchi, D.J.; B.A.Sc. [York], M.Sc. [Dalhousie]

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Wu, L.S.C.; B.Sc. [Brit. Col.]

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Douglas, A.N.; B.Sc. [Victoria]

Foreman, M.G.; B.Sc. [Queen’s], M.Sc. [Victoria]

Green, J.W.; B.Sc. [Victoria]

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Lee, D.K.; B.Sc. [Chosun-Korea], M.S. [Oregon]

Lee, K.S.; B.Sc. [Victoria]

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Ma, A.C.; B.Sc. [Victoria]

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Page, J.S.; B.Sc. [Brit. Col.]

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* * * Interchange Program
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*Chief of Division:*
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** Brown, R.M.; B.Sc. (Brit. Col.)
Denman, K.L.; B.Sc. (Calgary), Ph.D. (Brit. Col.)
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Mackas, D.L.; B.S., M.S. (Washington), Ph.D.
(Dalhousie)
Moore, D.F.; B.Sc. (McMaster)
Stone, M.

* Left in 1984
** Joined in 1984

B. Department of Environment

Atmospheric Environment Service

McBean, G.A; B.Sc. (Brit. Col.), M.Sc. (McGill),
Ph.D. (Brit. Col.)

Canadian Wildlife Service

Vermeer, K.; M.Sc. (Brit. Col.), Ph.D. (Alberta)

C. Department of Energy, Mines and Resources

Pacific Geoscience Centre

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Hyndman, R.D.; B.A.Sc., M.A.Sc. (Brit. Col.),
Ph.D. (A.N.U.)

*Head, Marine Geology (G.S.C.):*
Currie, R.G.; B.Sc., M.Sc. (Brit. Col.)
Chief Scientist, Pacific Geophysics Division (E.P.B.):

Law, L.K.; B.A Sc. (Toronto), M.Sc. (U. of Western Ontario), Ph.D. (Cantab)

Special Projects Officer (E.P.B.):

** Boyd, J.B.

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Chisholm, D.M.
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Yorath, C.J.; B.Sc. (Brit. Col.), M.Sc. (Alberta), Ph.D. (Queen’s)

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