THE JOURNAL
OF
THE ROYAL ASTRONOMICAL SOCIETY
OF CANADA

VOL. XLIX, No. 4 JULY-AUGUST, 1955 WHOLE No. 415

SEISMOLOGY IN BRITISH COLUMBIA

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INTENSIVE investigations of earthquakes in any area are often the result of a serious earthquake. In California, following the famous 1906 San Francisco earthquake, the interest in seismological study greatly increased, and it was at this time that the Seismological Society of America was formed. In British Columbia, the 1946 earthquake, although on a much smaller scale, showed the need for further study of the seismicity of the province. Probably as a direct result of this earthquake there is now a network of seismograph stations making it possible to locate most of the frequent small tremors in south-western British Columbia.

Seismological study in British Columbia was officially begun on January 1, 1899, when a Milne seismograph was purchased by the Dominion Government Meterological Service and installed on piers in the basement of the Customs Building near the inner harbour in Victoria. This was the second seismograph in Canada, being preceded by a similar unit in Toronto. The Victoria instrument, number 10 of the series built under Dr. John Milne's guidance for the study of earthquakes, is still in good condition in a museum at the Meteorological Station in Victoria. With the records from this seismograph (paper speed of 2.5 inches per hour, magnification 100), Mr. Baynes Reid, Superintendent of the Victoria Meteorological Office, and his successor, Mr. F. Napier Denison, studied earthquakes occurring at various places on the earth. Mr. Denison has written accounts of these studies in many previous issues of this JOURNAL.

In 1916 a new Meteorological Station was built at Gonzales Heights in Victoria, and the Milne seismograph was moved to a pier in the basement of the office building of the Dominion Astrophysical Observatory,

where it still rests. Mr. Denison built and put into operation at the Gonzales Observatory a similar horizontal-component instrument, and at about the same time added a Wiechert, 80 kgm. vertical-component seismograph. In 1922 two horizontal Milne-Shaw seismographs were located at Gonzales, and with the added sensitivity of these instruments the original Milne became a museum piece. During the period of operation of the Gonzales station several near by earthquakes were recorded. The strongest perhaps is that of December 6, 1918 which had its epicentre off Barkley Sound on the west coast of Vancouver Island. Mr. Denison has described some of the effects of this tremor in the 1919 issue of this JOURNAL.

In 1936 the Seismological Service of Canada was taken over by the Department of Mines and Resources, and henceforth the seismograph records were sent for study to the Dominion Observatory, Ottawa. The seismographs at Victoria however, continued to be operated at the Gonzales Observatory until 1939, when a vault to house the instruments was built at the Dominion Astrophysical Observatory, the instruments being out of operation for a few months during the transfer. The seismographs then came under the care of one of the astronomers, principally Dr. K. O. Wright, and Victoria became one of the stations of the Seismological Service of Canada like Ottawa, Saskatoon, Halifax, Seven Falls, and Shawinigan Falls. During this period the Victoria seismographs were the only instruments operating in British Columbia to record earthquakes. Mr. Denison, during the early 1930's, designed a seismograph similar to the Milne instrument and operated it briefly at Fernie, B.C. to record "bumps" occurring in the coal-mines near by, but no results of this work have been published. The University of Washington seismograph at Seattle has been in operation for many years, and its recordings with those of the United States Coast and Geodetic Survey seismographs at Sitka, Hungry Horse Dam, Butte and Grand Coulee Dam have been of considerable assistance to the Canadian seismologists in supplying information on local shocks.

Instruments

The 1946 earthquake indicated in a very forceful manner the need for better instruments for the study of earthquakes in British Columbia. To understand why, it is necessary to know that during an earthquake the earth usually vibrates at periods ranging from 0.1 second to 20 seconds. Newly-designed instruments indicate that periods as great as a minute or more may exist, but for an ordinary seismograph station it is sufficient to have instruments which will record waves with periods

of 20 seconds. For local earthquakes (a local earthquake being by definition one within 1000 kilometres of a seismograph station), the periods of the waves range from 0.1 to 1.0 second. It is the surface waves from very distant earthquakes that have the very long periods, or to express it in the usual way, the wave periods recorded increase with distance from the epicentre of the earthquake.

At the time of the 1946 earthquake the Victoria station was equipped with horizontal Milne-Shaw seismographs whose free period of vibration was 12 seconds. They were required to record wave periods of the order of 0.1 second and the results were very poor—in fact the instrument was broken after the first few seconds of the earthquake. (The Wiechert, a shorter-period vertical instrument, had been discontinued in 1945.) Furthermore, paper speeds on these early instruments were slow, the Milne-Shaw being 7.5 millimetres per minute. Reading of accurate time (to 0.1 second) is impossible with such records, and because severe earthquakes might be expected to occur again, it was decided that a modern seismograph should be installed at Victoria.

Where a station is to be equipped with only one sensitive seismograph it is generally agreed that that instrument should be of the vertical-component type. One such instrument designed to record short-period shocks consists of a seismometer (or pendulum) with a period of 1.0 second, driving a galvanometer with a period of 0.2 second, the seismometer being of the variable-reluctance type, with a mass of approximately 250 pounds. The period of such an instrument falls in the frequency range of local earthquakes. The photographic paper recorder revolves at a speed of 60 millimetres per minute, making accurate time-reading possible. A seismograph of this type was purchased in Pasadena, the home of its designer, Dr. Hugo Benioff of the California Institute of Technology, and installed during June 1948 on a pier in the vault at the Dominion Astrophysical Observatory. Immediately the seismologists at Ottawa became aware that earthquake activity near Vancouver Island was somewhat greater than had been indicated by the Milne-Shaw seismographs. Although the new instrument was out of operation for four months in 1949, between June 1948 and August 1951 it recorded 224 local earthquakes.

With only one instrument recording, the small tremors cannot be located because from one record only, distance alone can be computed. Thus, although it was known that there were many earthquakes occurring in the Vancouver Island area of British Columbia, it was not known where the majority of them were centred. When additional instruments became available at the completion of a programme of rock

burst study in Ontario in 1951, it was decided to establish two new seismograph stations in British Columbia. These stations were equipped with three-component (north-south, east-west and vertical) seismometers designed by Dr. P. L. Willmore, and made in Canada by the Sharpe Instrument Company. Their free period is approximately 0.3 second, and they are of the moving-coil type. Recording is done on a Sprengnether paper recorder through Turner 0.03-second galvanometers. One station was located at Alberni in August 1951 under the care of Mr. W. N. Burgess, and the second unit was placed upon a mountain near Horseshoe Bay a few miles from Vancouver, where Mr. W. S. Blacklock performs the daily record changes. A seismologist (the author) was transferred to Victoria from the Ottawa Observatory to be in charge of this network, and to investigate in detail the seismic activity in southwestern British Columbia. Since 1951, annual reports have been presented in the *Publications of the Dominion Observatory* under the title "Canadian West Coast Earthquakes 19—", discussing the results of these investigations. Late in 1954, the period of the instrument at Horseshoe Bay was increased by replacing the Willmore-Sharpe seismometers with Willmore-Watt instruments of the moving-magnet type. This was made necessary because the ships of the Black Ball Ferry dock some 100 yards from the seismic station; each time that a ship rammed into the pier when it landed, or churned up the water upon leaving the pier, the recording instruments were disturbed for three to four minutes. The longer-period seismograph acts as a filter, eliminating the disturbing "noise".

Meanwhile at the Dominion Astrophysical Observatory an addition was being made to the office buildings, and, on the ground floor of the new section an area was set aside for seismological equipment. Two cement piers were set on solid bedrock, one for the recorders and one for the seismometers, in a separate, insulated room. New Benioff three-component seismographs were installed. These short-period instruments operate at the same constants as the former vertical instrument. A three-record drum registers the earth motion in a separate room. The seismometers are each equipped with two series of coils, one to match the short-period (0.2 second) galvanometer, and one to match the long-period, (80 second) galvanometer. The complete unit is therefore capable of recording the very long-period waves of any earthquake, as well as the very short-period waves of a local shock. At a seismograph station the magnification of the instrument, usually adjustable, is limited by background noise. Near the coast these noises, or microseisms as they are called, are stronger than at central continental locations. The

microseisms range in period from 1-second waves caused by wind or surf to 6- to 8-second waves caused by huge lowpressure fronts moving over shallow seas. The magnification of the seismograph is adjusted so that the microseisms are not large enough to interfere with the reading of the onset of any earthquake. At Victoria the gain permitted is of the order of 40,000, or in other words, recorded amplitudes are about 40,000 times the actual ground motion. The Milne-Shaw instruments were moved to the new vault and continue to give satisfactory records of strong earthquakes. The Victoria seismograph station, as complete as any in Canada, includes a photographic darkroom, as well as an entrance hall which serves as a radio room and a record storage area.

Late in 1953 the Victoria office was asked to install three seismographs in the Crowsnest Pass area along the southern portion of the Alberta-British Columbia Boundary to record bumps in the coal-mines near by. These seismographs of the short-period Willmore-Watt type, using daylight recorders, are to be replaced later by one more-sensitive unit to be located in the mountains at about the latitude of Calgary.

The seismograph instruments described receive the earth-waves from a tremor and record them on photographic paper for future study. An important part of this study is the determination of the time of arrival of the various earth-waves at the respective seismograph stations. On each record a time mark is placed once a minute by a standard chronometer. (Our most accurate chronometer has a loss of time rate of ten seconds in five months.) To correct each station to absolute time it is necessary to record each day some standard time signal. At the network stations the CBC Dominion Observatory time signals are easily recorded. At the central station of Victoria, the time signals of the Mare Island, San Francisco station are recorded four times daily to provide more accurate time determinations.

Earthquakes

It is generally known that the circum-Pacific region is an active earthquake area, all portions from the Aleutian Islands in the north to southern Chile in the south having experienced a severe tremor at one time or another. The stretch of coast from Alaska to California was thought at one time to be relatively free of serious disturbances, but a glance at the earthquake history of British Columbia is sufficient to show that there have been strong earthquakes, although fortunately none was close enough to a populated area to arouse much attention. A strong jolt in 1872, probably centred about a hundred miles east of Vancouver, was perhaps the most severe event, although there were at that time few

people located in the area to feel and report it. On January 11, 1909 the Gulf Islands were jarred by a moderate tremor, and mention has already been made of the 1918 shock off the west coast. Between these events, minor tremors causing no damage were continually being felt.

At about 10:30 a.m. P.S.T. on Sunday, June 23, 1946 earthquake activity in British Columbia was suddenly brought to the attention of many residents of the south-western part of the province by an earthquake centred in the north Gulf of Georgia, approximately opposite Campbell River. Dr. Hodgson has described in detail the effects of this earthquake in the October 1946 issue of this JOURNAL. It is sufficient to note here that one life was lost, and many thousands of dollars of damage was done. The disturbance was measured at Pasadena as of magnitude 7, and from field evidence the intensity at the origin was VIII or IX. (Magnitudes are obtained from measurements of the recording of an earthquake made on a seismograph; intensities at the origin on a scale of XII are estimated from the visible after-effects of an earthquake and from reports of the experiences of persons feeling the shock.) Following the earthquake, only a few after-shocks were reported, and none was recorded, probably because of the insensitive nature of the seismographs at Victoria at that time. It was not until 1951 that seismic activity in the area could be studied with a network of stations, and then no after-shocks were recorded until late 1954. It is, however, unusual to have a major earthquake in an area, with no after-shocks.

There is no doubt that the Pacific region is subject to severe earthquakes, for between the time of the 1946 earthquake and the establishment in 1951 of the network of seismographs, two additional intense earthquakes were experienced in the coastal area. The lesser of the two, occurring on April 13, 1949, with epicentre near Olympia, Washington, was felt in areas of Canada adjacent to the state of Washington. No damage was reported in Canada, although in Washington damage amounted to more than one million dollars.

The stronger earthquake, occurring on August 22, 1949, at 8:01 p.m. P.S.T., with epicentre at 54.2°N., 133°W., northwest of Graham Island in the Queen Charlotte Islands group, was much greater in energy release at the centre of the disturbance. The Pasadena magnitude was 8.2, but no estimate is available of the intensity at the origin. This earthquake was followed on August 23, at 12:24 p.m. P.S.T., by an after-shock in itself as strong as the 1946 earthquake. The main event must be rated as one of the earth's major earthquakes.

On the Queen Charlotte Islands, although reports are scarce, the earthquake was felt severely. There is a report of a geologist working on the

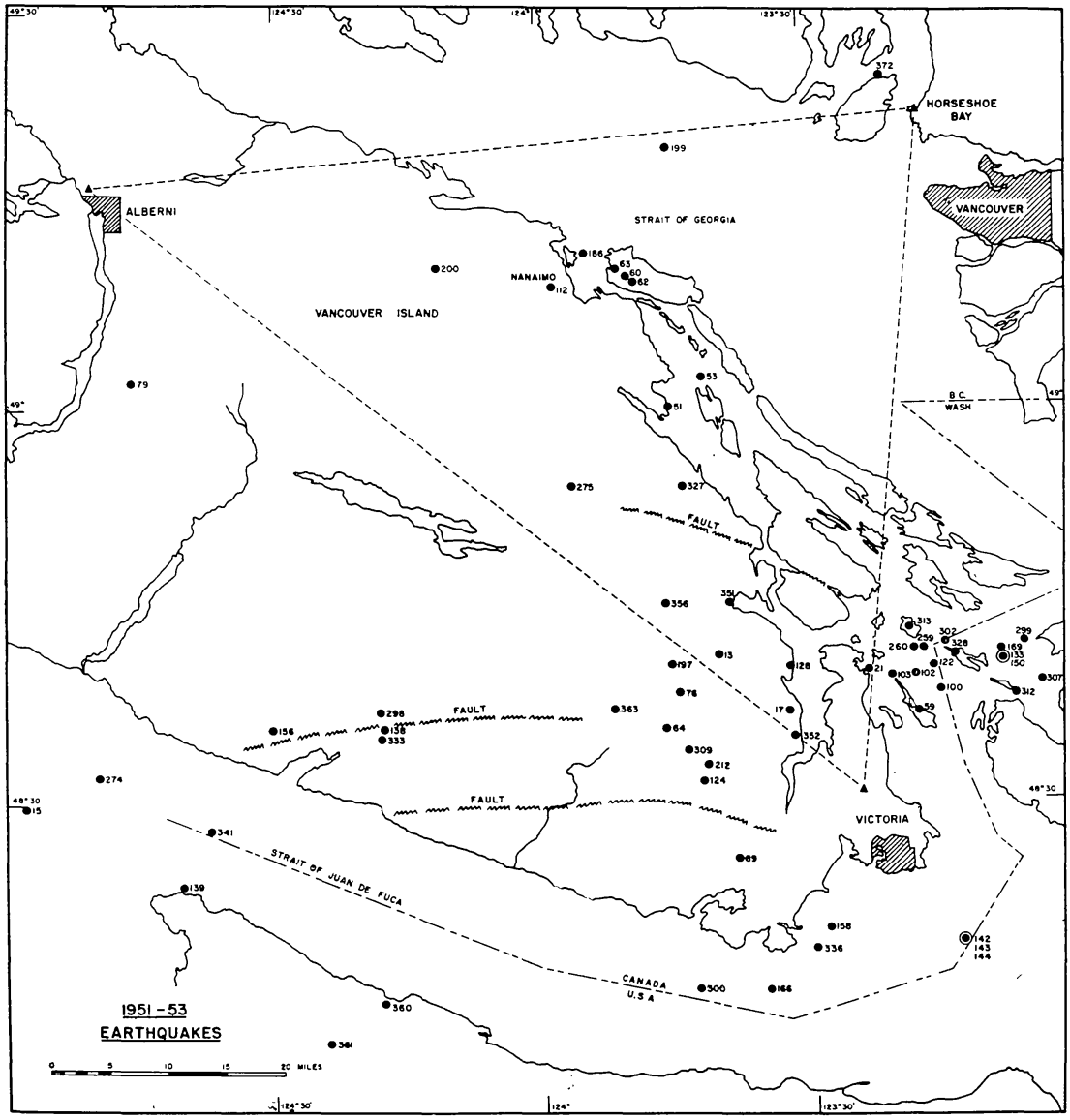
north-west tip of Graham Island who was unable to stand up due to the violent shaking of the ground. In the Lockport area two boat captains, who at the time were on land with their boats beached, reported that they had to hang on to trees to maintain their balance. They mentioned also that the water was swirling wildly where their boats were resting, and that there were many landslides. At Delkatla the bridge "writhed like a snake", and the ground was cracked. At a lodge near by, the horses could not be controlled even one hour before the event. The Prince Rupert Daily News states that just across Delkatla Slough the earth fissured, one crack fifty feet long and six inches across being so deep its bottom could not be seen. Many trees were felled, and in one house a piano was shifted. As far away as Prince George the people were alarmed and ran into the streets. At Cumshewa Inlet logging camp a tank containing many gallons of fuel oil was destroyed, at considerable loss to the owner. These are the only reports of damage that have come to our attention, but the earthquake was felt as far distant as Jasper to the east and Seattle to the south. Placing the origin in the Queen Charlotte Islands, this represents an area of some 2,220,000 square miles, half of which is under the ocean.

Following the earthquake, the residents of Cumshewa Inlet were reported as anxious to move out of the area, for between August 22 and October 1 they felt 107 after-shocks, that of August 23 being the most severe. At Victoria, a distance of 500 miles, the Benioff seismograph recorded 60 after-shocks.

Reports and written accounts of earthquakes in this area are scarce, but it appears that there have been many with epicentres just west of the Queen Charlotte Islands, and a few close to the mainland of British Columbia. This statement is based upon a search of newspaper files and upon reports of official epicentre-locating agencies such as the United States Coast and Geodetic Survey. While the Benioff seismograph alone was operating at Victoria, there were many earthquakes recorded but few located. Since August 1951 the network of seismographs has made it possible to assign an origin to many of the small local shocks, and during the intervening four-year period 622 earthquakes have been recorded, and of these 225 have been located. Naturally, the co-ordinates of the more precisely determined origins lie within the triangle made by the Horseshoe Bay, Alberni and Victoria seismograph stations. A map is included to show the distribution of epicentres within this triangle during 1951–52–53. Geological fault lines, mapped by Clapp in 1913, are indicated. The most concentrated group of epicentres shown is that in the Gulf Islands, from Saanich peninsula to Orcas Island. For

example, late in February 1952 three earthquakes with centres in this area were felt in Victoria and surrounding districts in as many days. No damage was reported, hence the intensity rating is of the order of III. The seismograph recordings indicate that none of these tremors could have been deeper than 15 miles.

The Saanich peninsula itself appears to have been free of any disturbance during this period, but across the Saanich inlet there were several tremors, again very small, but indicating to the seismologist what appears to be a more active area. In fact, there appears to be a major fault zone striking south from Nanaimo to Juan de Fuca Strait. This, however, is quite contrary to surface geological mapping, as in-



dicated by the fault lines shown on the map. Suggestions have been made that some of the seismograph recordings were caused by cave-ins in abandoned mine workings, since the seismic record does not differentiate between a man-made disturbance and an earthquake. In support of this suggestion, epicentres 60, 62 and 63 are along an abandoned mine-channel. Further, there is a possibility that some of the epicentres shown in the Strait of Juan de Fuca are depth-charge explosions, indeed many known cases of such explosions have been removed from the map. A few tremors occurred nearer Jordan River and along the fault line, one of them being felt as far distant as Vancouver.

The scattering of the other epicentres can perhaps be expected. Attention is directed to a group of earthquakes in the Mission-Abbotsford region. One earthquake which was felt there on February 6, 1952 was investigated in the field. It appeared that the earthquake was felt with about the same intensity from Stave Lake on the north to Sumas on the United States-Canada border, where the investigation ended. Several tremors appear to have occurred near Mount Baker, and there is the possibility that such may be associated with past volcanic activity. The strong earthquake of 1872 may perhaps have had its origin in this area, but an epicentre further east fits the evidence better. A few centres of disturbance have been located in the high mountains north of the Fraser River.

Seismic disturbances in south-western British Columbia appear to be divided into two groups, if apparently stray earthquakes are neglected. One zone of activity includes the tremors on Vancouver Island and possibly the few in Barkley Sound, the Gulf of Georgia, the Mission area and those along Jervis Inlet. This series of earthquakes extends south through the Seattle area and stops just south of Tacoma at the end of Puget Sound. The other zone lies further west of Vancouver Island at approximately 49°N. latitude and 130°W. longitude. This latter area is much more active than the zone lying closer to the continent, earthquakes of magnitude 6 to 6.5 being a regular occurrence. Perhaps the residents of the British Columbia coast are fortunate in having near by an area where energy can be released without harm to anyone.

Interest in seismic activity along the Canadian Rocky Mountain Trench has increased in recent years. United States geophysicists have pointed out that in Montana and further south the belt of moderate seismic activity parallels the trenches just west of the Rocky Mountain Range, but that the belt appears to end at the international border. At the present time we are investigating activity in that area with the seismographs of the Crowsnest Pass. There were a few small tremors in

the Rocky Mountain Range, and three disturbances are listed as having been felt in the trench area. However the intensity of these tremors was small compared with the intensity of those south of the border.

The three seismographs at Alberni, Horseshoe Bay, and Victoria make it possible to plot the seismic activity in the south-west corner of British Columbia, and it is likely that a similar triangle of stations placed anywhere along the coast would record equally as many earthquakes. With more sensitive seismographs, larger triangles could be used, so that within a few years the populated portion of the coastal region could well be covered. It would be interesting also to investigate the occurrence of earthquakes in the interior of the province. The purpose of such a coverage of seismic stations is to plot active seismic areas, so that it may be possible to say *prior* to the event that an earthquake such as that of 1946 may happen in one particular region but that it is unlikely to happen in another region a few miles away.