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BY

W. G. MILNE AND W. R. H. WHITE

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By W. G. MILNE and W. R. H. WHITE**

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ABSTRACT

In September, 1953, seismographs were installed in the Crowsnest Pass area of Alberta and British Columbia to study the 'bumps' which were occurring in the coal mines at Fernie and Coleman, and to investigate the possibility that they might be related to minor earthquakes in the area. During the initial phase of the work, three seismographs were operated at widely separated stations, two in the region of coal mines at Coal Creek and Coleman and one at Turner Valley, distant from any mining operations. Some earthquakes were recorded at all three stations and, in addition, many small disturbances were recorded by the seismographs located near the mines, especially by the instrument at Coal Creek. A closer network of radio-linked seismographs was then installed near Fernie, the records of which definitely established that the small disturbances were occurring in the mine workings, both active and inactive. No relationship was established between bumps and local earthquakes in the area.

This work was initiated as a cooperative effort with the Fuels Division of the Mines Branch, Department of Mines and Technical Surveys, which has undertaken a study into the phenomena of ground stress relief in underground mine workings.

* * *

INTRODUCTION

DEVELOPMENT of coal fields near the southern border of Alberta and British Columbia began around 1900, and there is evidence, as early as 1906, that the mines in the Fernie area of British Columbia were troubled by 'bumps'. This is a term used to describe underground disturbances in coal mines analagous to the 'rockbursts' associated with hard-rock mining in northern Ontario. The bumps are characterized by violent explosive activity of the walls, floors, or roofs of mine roadways, and project great quantities of broken rock and coal into such passageways. Another form of violent stress relief, called an 'outburst of gas and coal', expels large quantities of coal from the solid seam and is usually accompanied by the liberation of huge volumes of gas. In these latter disturbances the roof and floor rocks are seldom damaged. In this report the term 'bump' will be used to describe a disturbance known, either from seismic evidence or from direct observation, to have occurred in a mine. The term 'earthquake' will be used to describe a disturbance known to have originated at some distance from a mine, and until they are classified all disturbances will be called 'events'.

As part of their general study into the phenomena of ground stress relief, the Fuels Division of the Mines Branch, Department of Mines and Technical Surveys, has devoted considerable attention to the problem of mine bumps.

Obviously it would be desirable to know whether the bumps are the direct result of mining operations and always occur within the mine tunnels, or whether, as a result of large-scale regional geological activity in the past, there are residual stresses in the rock, the energy of which is released by the mining operations. The Fuels Division was also interested in the possibility that currently active geological activity is a contributing factor. It appeared probable that, if such stresses were present, there should be minor earthquakes occurring throughout the area; otherwise disturbances might be expected to be confined to the mine workings and their immediately adjacent areas. In order to investigate the problem, the Seismological Division of the Dominion Observatory was asked to set up seismographic stations in the area.

A network of three seismograph stations was installed in September, 1953, two located over active mine workings at Coal Creek and Coleman, and one at Turner Valley, some distance from the mountains and from mining operations. While the results of this initial investigation were not as informative as had been anticipated, nevertheless they did indicate that a few earthquakes occurred in the area of the stations, that there was little local activity recorded at the Turner Valley station, but that there was a great deal of local activity recorded at both the Coal Creek and Coleman stations. Since the local disturbances recorded at Coal Creek and at Coleman did not in any case register at both stations at the same time they were interpreted as being due to bumps related directly to the mining operations going on at one particular station. Unfortunately, since each disturbance was recorded at only one station, its precise location could not be determined, and further not one of the recorded disturbances was noticed by the miners. This lack of positive results led to the termination of the initial project in June, 1955, and the setting up of a more detailed investigation.

The second project, carried out during the summer of 1955, made use of a set of radio-linked seismographs, arranged to form a triangle in the immediate vicinity of the mine workings. These were installed at the Coal Creek mines near Fernie and, for a short period, in the Coleman area, and while the results indicated that no precise location could be determined for the source of recorded disturbances, it was

*Seismologists, Dominion Astrophysical Observatory, Department of Mines and Technical Surveys, Royal Oak, B.C.

reasonably certain that some of them originated within the mine workings. At the same time, the seismograph at Turner Valley was moved to Banff, a location free of background noise, thus permitting the instrument to be operated at full sensitivity. The recordings at the Banff station have confirmed that there are some earthquakes having their origins in this general area.

It should be noted that this project does not represent the first use of a seismograph to study mine disturbances. In the early 1930's, F. Napier Denison, of the Victoria Meteorological Observatory, operated a Milne seismograph at the Fernie mines. No report is available concerning this work, but considering the low magnification and the long period of the Milne seismograph, it is probable that few, if any, bumps were recorded.

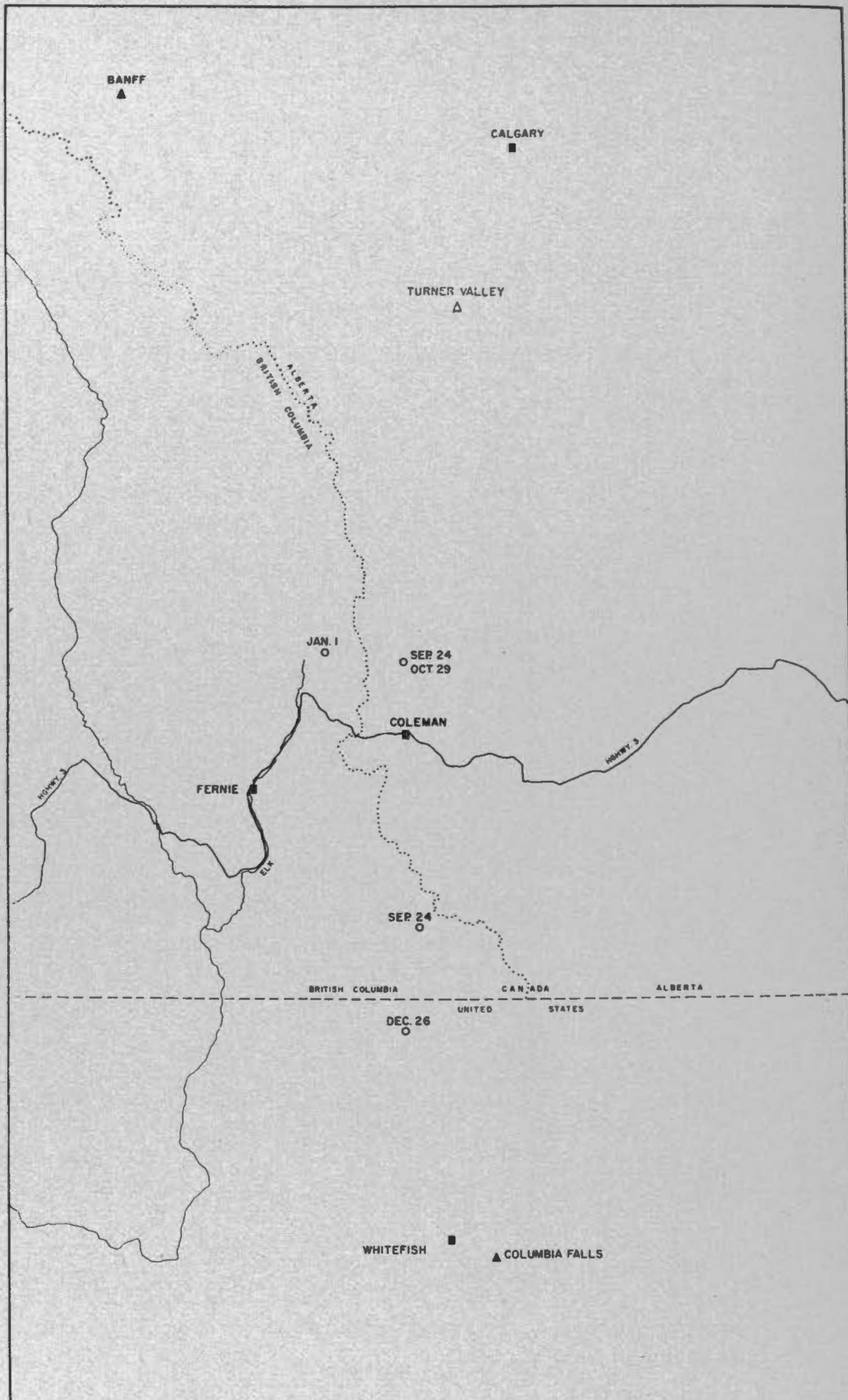

Figure 1.—Seismograph stations, and earthquakes located during initial programme.

Seismological Methods

This section will explain some of the terms of seismology used within this report. The record of a disturbance registered on a seismogram is much the same, whether the source of the disturbance in the earth is an earthquake, a blast, or a bump. At the time the event occurs, a compression wave and a shear wave are set up in the adjacent rock, and each is transmitted outward from the source in all directions. The former travels with about twice the speed of the latter and is called the *P* or compression wave. The slower wave is called the *S* or shear wave. Normally, both are recorded clearly and the difference in their arrival times can be read from the seismogram. If the speed of each type of wave is known, it is then possible to calculate the distance of the recording seismic station from the source. This method of obtaining distance from one record alone is called the *S minus P* method, or more simply, *S-P*. If one has an *S-P* distance of each of three seismograph stations from the centre of a common disturbance, it is possible to determine the location of the centre graphically on a map.

The *P*-wave arrives first at the station and hence usually appears as a sharp beginning on a quiet record, whereas the *S*-wave arrives at a time when the record is disturbed by the train of *P*-waves. Thus the time of beginning of the *P*-wave can be read more accurately. For this reason the *S-P* method of obtaining an origin is not used as much as are methods using the *P*-wave only, but in each case where an origin is determined from the *P*-wave arrival times at several seismographic stations, it is customary to compute *S-P* distances as well, to assure that no gross error has been made. The exact centre of a seismic disturbance within the earth is known as the 'focus'. Focal depth is the distance of the focus beneath the surface — in this investigation the focal depth has been assumed to be very small or zero. The 'epicentre' is the position on the earth's surface directly above the focus. The epicentral distance of a seismograph station is the distance from the epicentre to that station.

Initial Study of the General Area

Seismograph stations at Coal Creek and at Coleman, in the mining area, and at Turner Valley, east of the Rocky Mountain range, made up the initial network. Figure 1 shows a map of the area. Each station was equipped with a Willmore seismograph, made up of a Willmore vertical seismometer ($T_s = 1$ sec.) recording through a galvanometer with a period of 0.25 seconds. This equipment, shown in Figures 2 and 3, has the great advantage that it does not require a vault for its operation.

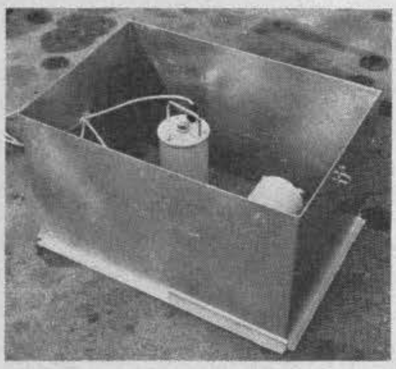

Figure 2.—Willmore-Watt seimometers in metal case.

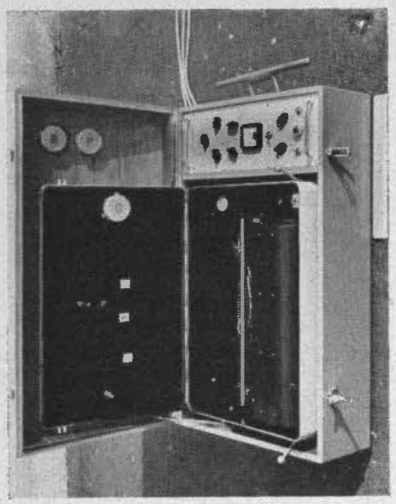

Figure 3.—Willmore-Watt 3-component recorder

The recorder can be installed in an ordinary room which need not be darkened. The seismometer can be buried in the ground in a waterproof metal container. For the three stations of this network, however, the instrument was set on bedrock and no special precautions were considered necessary.

At Coleman the seismometer was set on bed-rock a few hundred feet from the entrance to the McGillivray mine. About 700 feet of cable was used to carry the seismic signal to the basement of the mine office, where the recorder was installed. The recorder was operated with the paper speed set at 53.4 mm. per minute, and the records were changed daily. A chronometer was used to insert minute-marks on the record. At the beginning, no radio time-signals were available at Coleman but later radio station *CJOC* in Lethbridge agreed to broadcast the daily *CBC* time-signal at 18 hours *GMT* and these were recorded. In 1954 the *CBC* installed a booster station at Blairmore, only a few miles from the seismograph site, and from then on their signals were used. Noise from mining operations at Coleman necessitated operation of the instruments at approximately one-third full sensitivity.

Table I.—Earthquakes Recorded at Coleman Fernie, Sept. 1953 to June 1955

Date	Time h.	(G.M.T.) m.	Remarks
1953 November 28	23	57	Coleman distance 125 miles, Fernie distance 116 miles.
December 10	09	14	Coleman distance 159 miles.
December 25	17	15	Approximately 44 miles (probably south) from Coleman
December 26	15	18	Coleman distance 54 miles, Fernie distance 49 miles, Hungry Horse distance 44 miles. Epicentre is 114°.5 W, 48°.9 N; about 10 miles south of the Canada-United States border.
1954 January 1	06	11	A small tremor (or bump) within 5 miles of Coleman.
September 9	18	07	Distance about 136 miles from Coleman. This was not recorded at Hungry Horse, hence the epicentre must be west or north of Coleman.
September 10	20	50	Approximately 25 miles from Coleman.
September 24	07	30	Hungry Horse and Coleman data indicate an origin 20 miles north of Coleman.
September 24	23	02	Hungry Horse and Coleman data indicate an origin south of Coleman near the border.
September 26	19	16	Probably close to Fernie. Recorded at Hungry Horse and Coleman.
1954 October 29	05	22	Epicentre about 19 miles north of Coleman, from Hungry Horse data.
November 4	21	38	Fernie and Coleman readings indicate an origin north of Coleman.
November 20	22	19	Distance 12 miles north of Coleman.
November 29	23	33	Approximately 10 miles from Coleman.
1955 January 1	21	19	Epicentre northwest of Coleman 20-30 miles.

At Coal Creek, the seismometer was placed on bed-rock about 900 feet from the recorder, located in the lamp-house at the mine office. The recorder was operated at a paper speed of 13.5 mm. per minute, and records were changed every four days. Time-signals were received here only about 25 per cent of the time, due to the high level of local static on the radio. Again, the sensitivity control was set at one-tenth or one-third maximum due to mine noise. Unfortunately, a conveyor belt, operating during two of the three shifts the mine worked, ran past the seismometer and disturbed the records greatly.

The processing of photographic records for both Coleman and Fernie was carried out in an office maintained by the Mines Branch at Coleman.

Seismic records were obtained for about a year at Turner Valley under fairly quiet background conditions. The recorder was installed in the basement of the operator's house and the seismometer was set on a nearby outcrop of rock. Later, the house was moved, necessitating the transfer of the recorder to another basement nearby. Unfortunately, chronometer troubles combined with lack of radio time-signals interfered with the accuracy of time-control for much of the time. However, a fairly continuous record of ground movement was obtained over the period of a year, and it appears that no local earthquakes occurred in the Turner Valley area during that time.

Events recorded on the network seem to fall into two groups. The first group have a fairly large *S-P* interval, and are thus events that occurred a considerable distance from the recording station. The second group have an *S-P* interval so small that the events must have occurred very near to the seismograph stations. Disturbances of the first group are regarded as earthquakes, although there is no report of any of them having been felt.

From September 1953 to June 1955, a total of sixteen events were recorded at Fernie and Coleman which are, by the above definition, earthquakes. Table I lists these disturbances, and their epicentral distances, computed by the *S-P* method. The travel-time curves used to obtain the distances are those computed by J. H. Hodgson (1) in his study of the Canadian Shield. In those cases where readings from the United States Coast and Geodetic Survey station at Hungry Horse were available, epicentres were determined and are shown in Figure 1.

Events belonging to the second group were much more numerous, although they were confined entirely to the Fernie and Coleman stations. There is no case of an event local to one station being recorded at another, indicating that these disturbances must have been very small. No attempt is made here to list all such small shocks for the whole period, but Table II contains the list for a typical interval. The mine offices attempted to keep a record of bumps felt underground and these lists were compared with the list of recorded events. As indicated in Table I, local events recorded by the seismograph were not felt, and those felt and reported were not normally recorded by the seismograph.

A severe outburst of gas and coal occurred at the Elk River mines, Fernie, on March 9th, 1955, causing the collapse of the walls of a tunnel where miners were working, and resulting in casualties. During the four-day period covering the time of the bump, the Fernie seismograms recorded a total of seventeen very sharp events. In addition, two very weak disturbances were recorded at the time the bump was reported to be felt. Coleman seismograms show no trace of any of these events. This incident strengthened the previous conviction that the events the miners feel are usually not recorded, and that the numerous very sharp events the seismograms record are usually not felt in the workings.

Since the spacing of the stations made the determination of the centre of small disturbances impossible, it was decided to move the stations so as to form a small triangle over one mine, and thus to concentrate on

TABLE II.—TYPICAL SERIES OF EVENTS RECORDED BY FERNIE AND COLEMAN SEISMOGRAPHS, WITH MINING COMPANY RECORDS OF BUMPS REPORTED TO BE FELT DURING THE SAME INTERVAL

Date		Location	Time	M.S.T.	Remarks
1954			h.	m.	
September	17	Coleman	20	14	Small bump recorded
	20	Coleman	15	25	Medium bump recorded
	21	Coleman	12	00	Sharp bump felt. Not recorded.
	23	Coleman	12:00	13:00	Small bump felt. Not recorded.
	24	Coleman	01	11	Small bump recorded
	24	Coleman	13	24	Medium bump recorded
	25	Fernie	05	50	Small bump recorded
	26	Fernie	07	30	Small bump recorded
	26	Fernie	19	06	Small bump recorded
	26	Fernie	19	28	Small bump recorded
	27	Coleman	00	48	Small bump recorded
	28	Fernie	13	20	Small bump recorded
	28	Fernie	13	40	Small bump recorded
	28	Fernie	15	05	Small bump recorded
	28	Fernie	18	01	Small bump recorded
	28	Fernie	19	15	Small bump recorded
	28	Fernie	21	35	Small bump recorded
	28	Fernie	23	30	Small bump recorded
	29	Coleman	05	52	Medium bump recorded
October	1	Fernie	00	08	Small bump recorded
	1	Fernie	01	26	Small bump recorded
	1	Fernie	05	42	Small bump recorded
	1	Coleman	15	35	Small bump recorded
	2	Fernie	01	31	Small bump recorded
	2	Fernie	05	35	Small bump recorded
	2	Coleman	18	30	Small bump felt. Not recorded
	3	Coleman	19	15	Small bump recorded
	6	Coleman	14	12	Small bump recorded
	7	Coleman	22	00	Sharp bump felt. Not recorded
	8	Coleman	08	36	Sharp bump felt. Not recorded
	8	Coleman	09	43	Sharp bump felt. Not recorded
	8	Coleman	12	45	Sharp bump felt. Not recorded
	8	Coleman	15	15	Sharp bump felt. Not recorded
	10	Coleman	20	42	Small bump recorded
	11	Coleman	01	00	Small bump recorded
	12	Coleman	16	15	Small bump recorded
	14	Coleman	17	00	Sharp bump felt. Not recorded

finding the source of such events. In June 1955, the initial programme was terminated in favour of a detailed two-month investigation. One conclusion drawn from the initial programme is that there are a few, but not many, small local earthquakes in the area of the Rocky Mountain range. It is not possible to state definitely whether they are sufficient in number and size to indicate the existence of stresses that may be an indirect cause of bumps.

DETAILED STUDY OF TWO SPECIFIC MINING AREAS

In order to be able to locate the small events within useful limits, it is necessary that the records yield the time to better the 0.1 second. Radio time-signal reception in the Fernie area was so erratic that the required accuracy could not be obtained from three seismograph stations, each recording time independently of the other. For this reason use was made of radio-linked seismographs built for the project by Dr. P. L. Willmore. Three seismograph stations were provided; two of these transmitted their output by shortwave radio to a central point where their signals were recorded, together with the output of a third seismograph recording directly on a single drum. With this system, time control would be limited only by the accuracy of reading records, because the necessity of obtaining corrections for three stations to a standard of time had been eliminated.

Table III is a list of the seismograph instruments used, together with their known constants. At the master station a direct-recording seismograph arrangement was used. The output of the Willmore-Watt seismometer was recorded through a 0.25-second galvanometer on a Willmore recorder. At the transmitting stations the output from the seismometers was amplified, and then used to frequency-modulate an audio-tone, which in turn amplitude-modulated a 148-megacycle carrier. A two-channel receiver was used at the master station to receive the signals from the two transmitting sites. The output of each channel of the receiver was fed into a 30 c.p.s. galvanometer in the Willmore recorder, and the seismic information from all three stations was recorded on a single sheet of photographic paper. The driving mechanism in the recorder was set to rotate the drum at a paper speed of 53.4 mm. per minute. Use of the three galvanometers necessitated changing the records three times daily. This was done at 08:00, 15:00, and 23:00 hours P.S.T. The direct recording seismograph was operated at full sensitivity, equivalent to a magnification of about 100,000 at the period of the waves being recorded.

TABLE III.—SEISMOGRAPH INSTRUMENTS USED

STATION	SEISMOMETER	GALVANOMETER	RECORDER
Master Station	Willmore-Watt. Period 1 sec.	Turner Period 0.25 sec.	Willmore
Transmitting Stations	Willmore-Watt. Period 1 sec.	Turner Period 0.03 sec.	Willmore

(1) HODGSON, J. H., *A Seismic Survey in the Canadian Shield;* Publications of the Dominion Observatory, Vol. 16, No. 5, 1953.

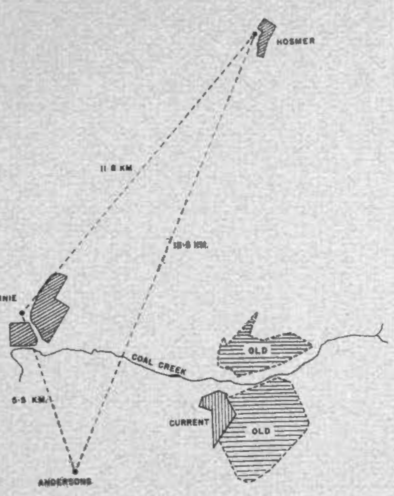

Figure 4.—Sketch-map of Fernic area, showing location of seismic stations.

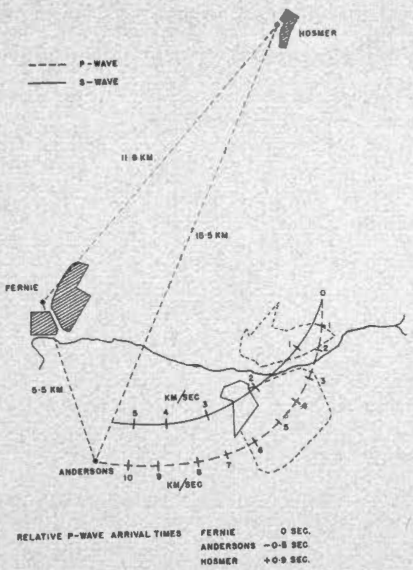

Figure 5.—Series of bumps located at Fernie.

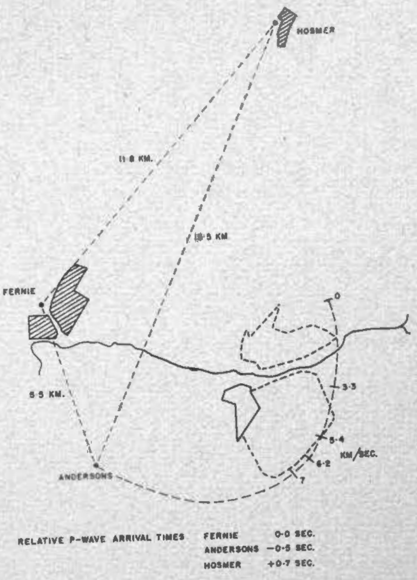

Figure 6.—Series of bumps located at Fernie.

The first triangle of stations was placed to study seismic activity near the Elk River colliery. In choosing sites for the stations the requirements included access to power, line of sight from the two transmitting stations to the master station, and, if possible, an outcrop of bedrock on which to place the seismometers. An advantage of the Willmore seismograph is that, where bedrock is not available, it is considered to be satisfactory to bury the seismometer in solidly packed earth. Such proved to be necessary in the case of this triangle. Due to the topography of the area the triangle took the form shown in Figure 4, the master station being placed at the apex of the elbow in the Elk River valley, just outside Fernie. The transmitting stations were placed in opposite directions along the valley, at Hosmer and Anderson's farm.

The geographical co-ordinates of the stations were obtained by plotting the positions on a large-scale map (scale 1 in. = 0.4 mile). These are shown in Table IV. The sides of the triangle have lengths 5.5 km., 11.8 km., and 15.5 km.

The radio seismograph network was in operation at Fernie from July 12th, 1955, to August 12th, 1955. On August 12th the network was moved to the Coleman area, where the master station was located near the Chinook Cabins (Sentinel), and the transmitting stations near the Greenhill mine, north of Blairmore, and at the Ironstone Fire Range station, south of Coleman.

TABLE IV.—CO-ORDINATES OF FERNIE NETWORK OF SEISMOGRAPH STATIONS

	LATITUDE	LONGITUDE	ELEVATION
Fernie..........	49° 30. 4'N.	115° 04. 4'W.	3,250 feet
Hosmer..........	49° 35. 3'N.	114° 58. 1'W.	3,500 feet
Anderson's Farm..	49° 27. 6'N.	115° 03. 1'W.	3,250 feet

TABLE V.—CO-ORDINATES OF COLEMAN NETWORK OF SEISMOGRAPH STATIONS

	LATITUDE	LONGITUDE	ELEVATION
Sentinel..........	49° 38. 0'N.	114° 34. 8'W.	4,500 feet
Ironstone........	49° 34. 2'N.	114° 30. 0'W.	6,800 feet
Blairmore........	49° 37. 7'N.	114° 26. 6'W.	5,000 feet

The co-ordinates for the Coleman sites are given in Table V, and the Fernie-Coleman network is shown on the maps of Figures 7 and 8. Records were obtained at Coleman from August 15th to August 29th.

From the records obtained for the thirty-one days during which the radio seismographs were operated at Fernie, a total of thirty events were analyzed. A few other events are omitted from the discussion because of their doubtful appearance on the records. Of the thirty events discussed, the relative times of the arrival of their *P*-waves at the three stations suggest that fifteen had their origin in the same area. These fifteen are listed in Table VI. Relative *P*-wave arrival times are given, the arrival time at the master station being taken as zero. In addition, the corresponding arrival times of the *S*-wave are shown. The values of *S-P* for each station agree well for this series of events. The fifteen events recorded by the direct-coupled seismograph are similar in appearance, except for amplitudes.

The determination of an epicentre for any event is, of course, dependent upon the seismic-wave velocities in the area. Such velocities have not been determined in southwestern Alberta (with the possible exception of work done by oil-prospecting groups). It has been established, however, that crustal *P*-wave velocities fall between 5.6 and 6.2 km./-sec. The method used in the investigation to locate the centres of recorded events as lying within the area of the mine camp did not require that the *P*-wave velocity be specified more accurately than that it falls within the above range.

Stations on the network were assumed to have equal elevations and,

TABLE VI.—BUMPS RECORDED AT FERNIE (SUMMER 1955)

No.	Date	Approx. Time MST h.m.	Phase	Arrival Times Fernie secs.	Hosmer secs.	(Relative) Andersons secs.	Fernie Double Trace Amplitude (mms)
5	July 22	21:00	P	0	0.8	-	10
			S	1.5	-	-	
6	July 24	02:30	P	0	0.9	-	4
			S	1.5			
7	July 24	03:30	P	0	0.9		3
			S	1.6			
9	July 24	23:00	P	0	1.0		7
			S	1.5			
11	July 26	07:00	P	0	0.9	-0.5	1
			S	1.5	3.7	+0.7	
13	July 26	24:00	P	0	0.7	-0.5	3
			S	1.5	3.6	+0.6	
14	July 27	03:00	P	0	0.5	-0.5	2
18	July 28	15:00	P	0		-0.8	4
			S	1.5			
19	July 29	09:30	P	0		-0.5	3
			S	1.5			
20	July 30	02:00	P	0		-0.5	1
			S	1.5			
21	July 30	03:00	P	0		-0.5	
			S	1.5			
22	July 30	06:00	S-P	1.5			1
27	Aug. 9	00:10	P	0	0.9	-0.5	2
			S	1.5	3.6	+0.5	
29	Aug.11	01:30	P	0	1.1		2
			S	1.5			
30	Aug. 12	04:00	P	0		-0.4	1
			S	1.5			

TABLE VII.—EVENTS RECORDED AT FERNIE (SUMMER 1955)

Map No.	Date	Approx. Time MST	Phase	Arrival Fernie	Times Hosmer	(seconds after nearest minute mark) Andersons
1	July 17	13:30	P		11.1	10.8
			S	12.7	13.0	12.5
2	July 17	13:35	P		45.7	45.6
3	July 17	13.44	P		14.0	13.6
4	July 17	13:45	P			15.9
			S		19.6	19.3
8	July 24	14:00	P	43.0	41.3	
			S	49.3		
10	July 25	16:00	S-P	4.1		
12	July 26	12:00	S-P	5.7		
15	July 27	14:30	P	57.3	58.0	
			S	58.0		
16	July 28	11:30	P	13.8	11.7	14.4
			S	17.3		
17	July 28	13:00	P	38.4	37.7	40.0
23	July 30	11:00	P	30.4	29.9	31.6
24	July 31	08:00	S-P	5.0	-	
25	Aug. 3	16:30	P	31.5	31.4	31.7
			S	35.0		
26	Aug. 8	13:15	P	49.9	50.5	47.8
28	Aug. 9	11:30	P	09.7	08.3	10.0
			S	15.4	12.7	16.0

TABLE VIII.—EVENTS RECORDED AT COLEMAN (SUMMER 1955)

Event No.	Date	Approx. Time MST h.m.	Phase	Arrival Times (Secs. after nearest min.) Sentinel	Blairmore	Ironside	Sentinel Double Trace Amplitude
1	Aug. 22	14:30	P	34.7	-	35.8	1.0 mm.
			S	37.4			
2	Aug. 24	16:30	S-P	2.7s.	-	-	1.0 mm.
3.	Aug. 24	18:15	P	24.4	-	25.1	0.5 mm.
			S	29.1			
4	Aug. 25	14:45	P	25.4	27.2	26.7	1.0 mm.
			S	28.1			
5	Aug. 26	15:30	P	23.9	-	-	1.0 mm.
			S	26.6			

in the absence of any evidence to the contrary, all events were assumed to have a surface focus. Differences in arrival times between pairs of stations were calculated for the fifteen events listed in Table VI. The locus of all possible locations for each event was then determined, assuming values of *P*-wave velocities from 0 to 10 km./-sec. (see Figures 5 and 6).

Diagrams showing the locus for each event were forwarded to the Mines Branch in Ottawa, where the approximate area covered by the mine workings was indicated. In each case, when a reasonable value for the velocity of the *P*-wave is used, the epicentre of the event falls within the area of the mine camp. Only if the velocity is assumed to be greater than 6.5 km./sec. or less than 4 km./sec. does the epicentre lie outside the area of the mine camp. It thus appears reasonable to regard all fifteen recorded events as bumps, associated with the mining operations. It should be pointed out, however, that not one of the fifteen events was reported to be felt. It is probable that the small events recorded during the initial programme can be grouped with the fifteen events here identified as bumps.

It was pointed out earlier that the *S*-waves are normally used to check the computed epicentre location. When this was done for the fifteen events noted above, and the results were plotted in the same manner as for the *P*-wave data, it was found that the two loci, the *S*-wave and the *P*-wave curves, did not coincide. The explanation for the disagreement may be that the *P*-waves and the *S*-waves did not travel similar paths to the seismograph, due to the variable content of the surface layers in the area. The *P*-wave data are considered the more reliable, since, as already pointed out, the *P*-wave arrives first at the seismograph station and, falling on an undisturbed record, can be read more accurately.

Table VII contains a list of events recorded at Fernie whose centres did not lie within the mine area, and which thus, by definition, represent earthquakes. The epicentres of these events were computed by the *S-P* method, using the travel-time curves of Hodgson (1).

(1) *Op. cit.*

Caution should be exercised in relating these epicentres with known faults until such time as the velocities used can be checked by experimental means.

One of these earthquakes was of sufficient size to record at the Banff and Hungry Horse stations as well. Its epicentre, shown as number 16 on the map of Figure 7, probably represents the most accurate determination in the group of earthquakes listed in Table VII and plotted in Figure 7. In some cases the locations are in doubt because only two stations have recorded the events. As was the case for the bumps recorded, none of the recorded earthquakes was felt.

At Coleman there were fewer events; those that occurred are listed in Table VIII. Four of them appear to have a common origin.

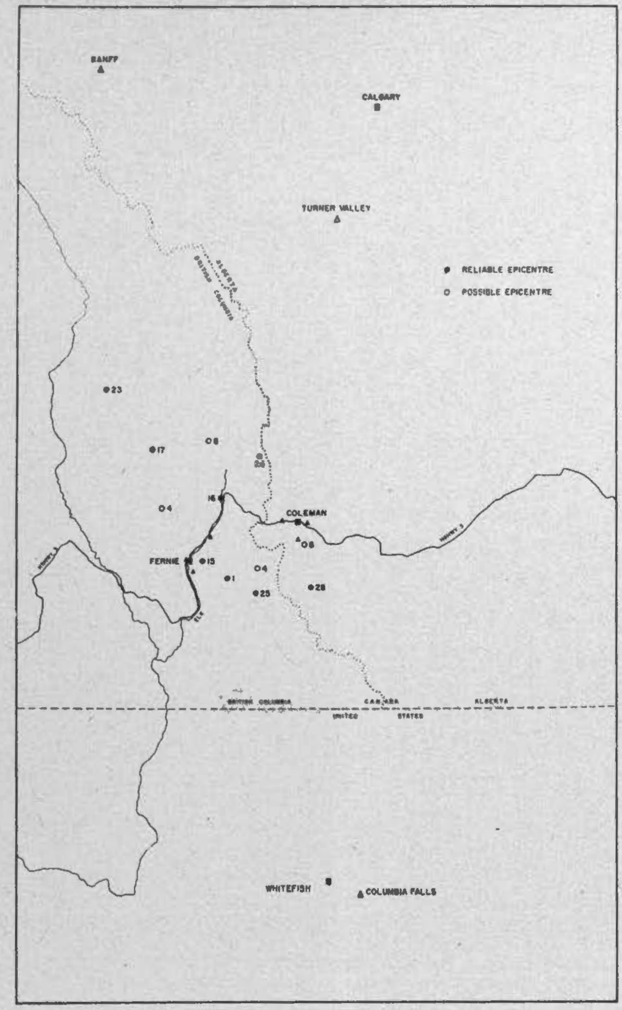

Figure 7.—Earthquakes located from Fernie network.

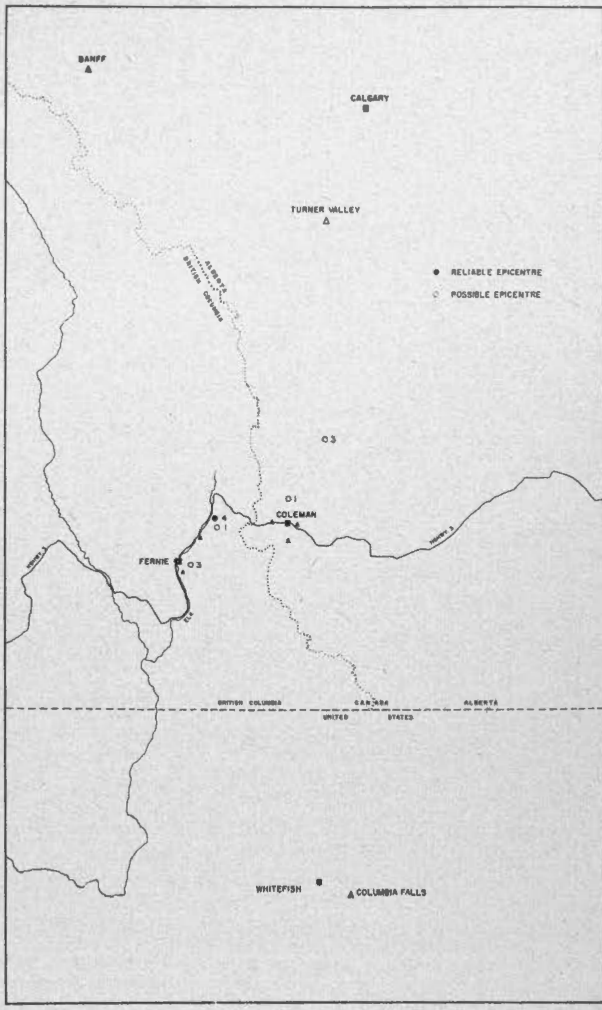

Figure 8.—Earthquakes located from Coleman network.

Their epicentres are plotted on the map of Figure 8. Portions of the seismograms for some of the events are shown in Figure 9.

Banff Station

In July 1955 the Turner Valley seismograph was moved to Banff where it could be operated at maximum sensitivity. Since this location is in the general area under study, and since there have been to date almost two years of continuous seismic recording, the list of earthquakes recorded are of interest in this study. While there is a possibility that some of the minor disturbances are outbursts from the mines at nearby Canmore, the majority of them are at considerably greater distances, and are thus considered to be earthquakes. Table IX is a list of such tremors for 18 months beginning July 1955. The computed distances of the epicentres from Banff are shown, but the locations can seldom be determined.

Conclusion

There are small earthquakes occurring in the area extending from the United States border to at least as far north as Banff, and from the foothills across the Rocky Mountain range. The records obtained at the stations in the Crowsnest area and at Banff indicate that the distribution of epicentres is random. During the three-year period covered by our investigation, none of the local earthquakes recorded had a magnitude greater than 3, and none was felt.

During the initial programme it was apparent that bumps or local events were being recorded at Fernie and Coleman, and not at Turner Valley. On the Fernie records, these bumps were more frequent and stronger than on the Coleman records. Few correlations are possible between events recorded by the seismographs and bumps reported to be felt in the mines. However, during the investigation at Coleman, work in the mines was continually decreasing; so was the number of recorded bumps. At Fernie there were four to five bumps recorded on an average day.

During one of the weeks that the radio seismograph network was in operation at Fernie, the miners were on annual holiday and mining operations had ceased. During this time no small local events were recorded, but when the mine reopened, the disturbances resumed. This appears to be the most definite correlation obtained between mining activities and the recording of bumps. It is evident that most of the bumps do occur in the active mine workings or in older worked-out areas. The latter source may partly explain the fact that most recorded bumps are not reported to be felt. The instruments, in particular the lack of sufficiently precise time control, prevented the bumps being located more definitely.

There seems to be no correlation between earthquakes and bumps. Following a tremor, the number of

Table IX.—Events Recorded at Banff, 1955-1956

Date 1955	Time GMT h.m.	Banff S-P (secs.)	Banff Distance (miles)	Distance from Hungry Horse
July 28	18:45	23.0	133	121
Aug. 15	01.57	23.4	135	103
16	18:49	4.1	20	
31	20:31	22.0	127	
Oct. 5	19:16		close	
7	12:57	14.1	69	19
14	15.37		close	
22	21:19		close	
Nov. 21	21:36		close	
Dec. 1	14:34	4.3	21	
6	21:19	4.0	19	
8	17:54	5.4	25	
9	16:18	4.7	23	
21	03:50	22.3	130	121
1956				
Jan. 12	22:22	1.9	14	
Mar. 2	19:00	5.8	28	
17	22:15		close	
Apr. 11	22:24	3.5	16	
14	11:17	23.0	215	
16	21:52	5.5	26	
18	18:47	6.3	31	
21	17:37		close	
Sept. 14	21:27	7.5	36	
22	15:17		close	
Oct. 4	00:13	1.0	9	
7	16:56	1.0	9	
7	22:58	1.0	9	
9	21.39	0.9	8	
9	23.42	4.3	20	
12	01:08	0.8	7	
14	22:48	1.3	11	
Oct. 17	01:28	0.9	7	
18	00:38	1.0	9	
18	01:09	1.1	10	
Nov. 2	21:33	1.0	9	
2	22:30	4.0	18	
5	22:42	3.8	17	
10	20:24	1.7	13	
15	23:22	3.8	17	
16	22:38	3.8	17	
17	20:12	3.2	15	
22	22:56	11.4	54	
24	22:58	0.9	7	
27	23:02	0.9	7	
Dec. 4	18:55	3.3	15	
4	20:32	3.3	15	
21	19:41	2.0	14	
24	23:27	1.6	12	

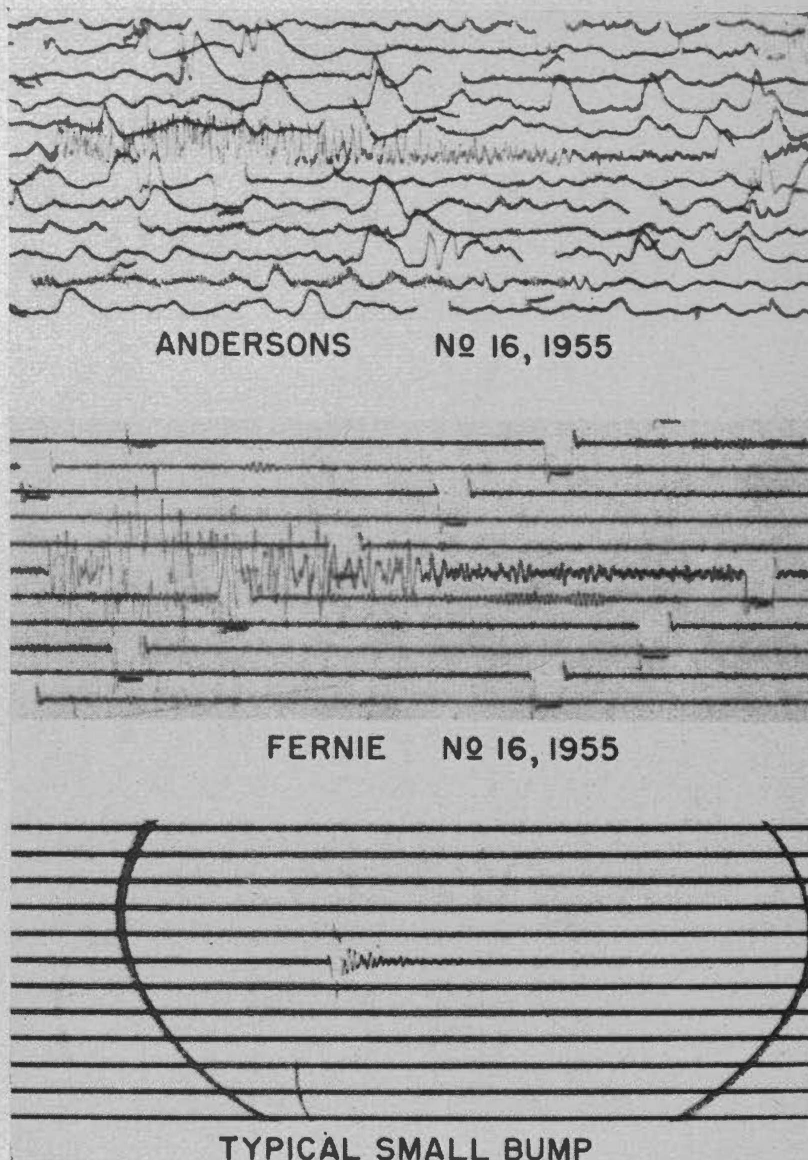

Figure 9.—Typical records of bumps.

bumps did not increase, but this was not expected since the earthquakes were weak, and none was felt. Data now being accumulated at the Banff station will help in the future to locate more precisely the earthquakes that occur in the area.

Acknowledgments

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