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PRELIMINARY REPORT ON
THE VALEMOUNT EARTHQUAKE OF MAY 14, 1978

by

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SEISMOLOGICAL SERVICE OF CANADA

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ABSTRACT

At 2237 GMT on May 14, 1978 a magnitude 4.8 earthquake occurred in the Canadian Rockies near the Mica Dam reservoir, McNaughton Lake, south of Valemount, B.C. Initial investigations suggest it was not a reservoir induced earthquake.

The earthquake was within the seismic array monitoring the reservoir which allowed a well-constrained epicentre (52.65°N, 118.87°W) and focal depth (8 km) to be determined. There were no foreshocks but a normal aftershock sequence. Preliminary interpretation of the focal mechanism indicates predominantly right-lateral strike-slip faulting along the strike of the mountains with a significant thrust component. A well-developed Lg phase was recorded to the south of the earthquake. The isoseismals are elongated in a north-south direction and intensity attenuation with distance to the south is similar to the relationship for eastern North America.

PREFACE

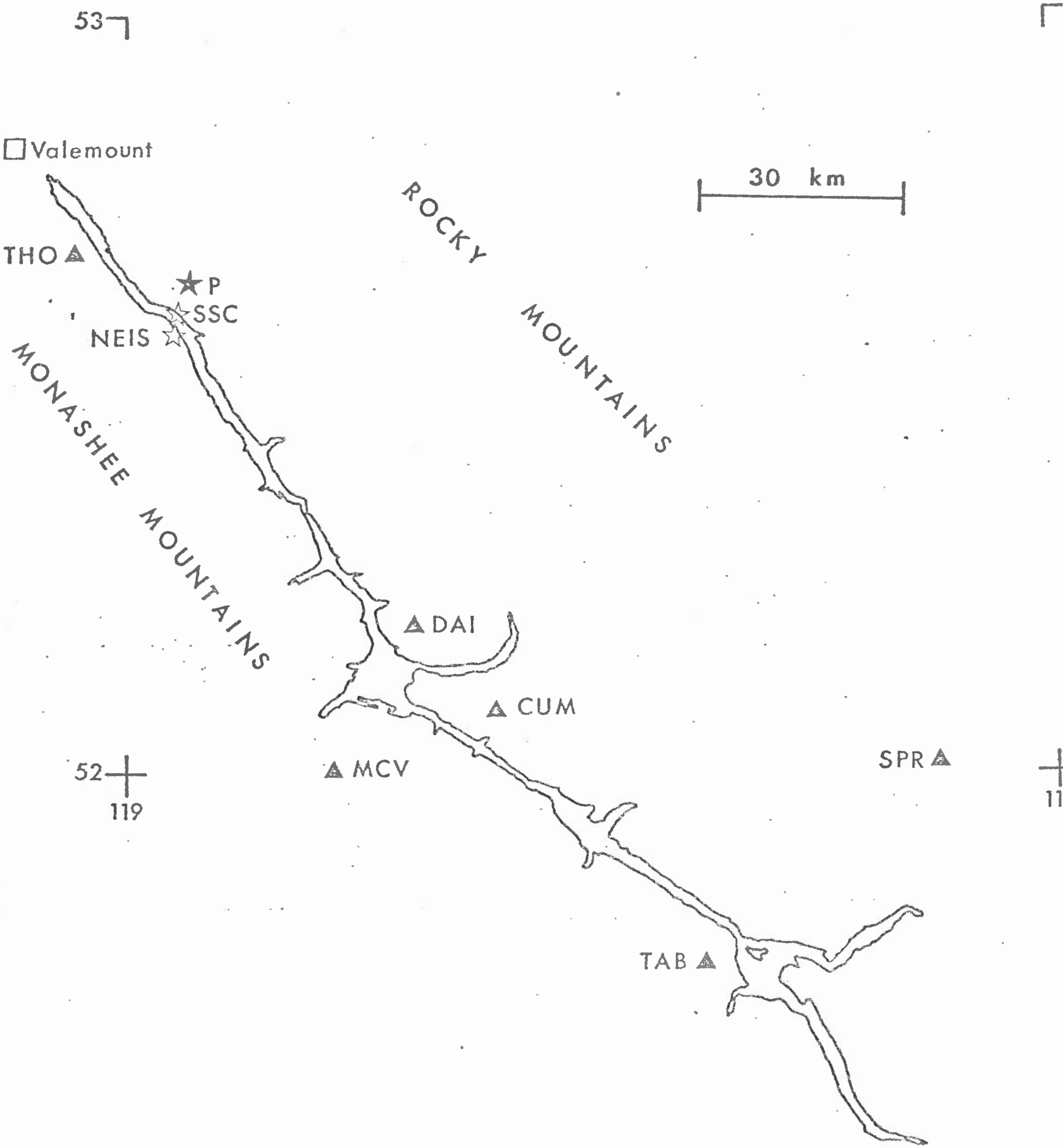
In this preliminary report, we present the results of our study on the epicentral location, focal depth, magnitude, foreshocks and aftershocks, a P nodal mechanism solution and the intensity data. Our complete study will provide a P nodal solution based on a more complete data set. H.S. Hasegawa plans to supplement our present investigation with a surface wave study of the mechanism and focal parameters. In addition we plan further studies on the aftershocks and the Lg propagation.

INTRODUCTION

On 14 May 1978 an earthquake occurred near the town of Valemount in eastern British Columbia (Fig. 1) and was felt over an area of approximately 50,000 km^2. The provisional epicentres of both the Seismological Service of Canada (SSC) and the U.S. National Earthquake Information Service (NEIS) placed the epicentre approximately 30 km southeast of Valemount. The Seismological Service of Canada assigned a Nuttli magnitude m_{bLg} = 4.7, a Richter magnitude M_L = 4.8, and a surface wave magnitude based on the Marshall and Basham (1972) formula of 3.9 while the National Earthquake Information Service assigned a body wave magnitude m_b = 5.0.

These epicentres are very close to the Rocky Mountain Trench which in this section contains McNaughton Lake, the reservoir behind the Mica Dam. Changes in seismic activity have now been related to the filling of large reservoirs in over thirty cases (Simpson, 1976). However for this reservoir, at which filling was initiated in 1973 and full load ($h = 190$ m, $V = 25 \times 10^9 m^3$) first achieved in 1976, no previous seismicity has been detected which can be directly related to reservoir loading (Ellis et al., 1976). This is the largest earthquake observed in the reservoir region since initiation of loading. Its possible relationship to the reservoir is therefore of particular interest. Further, the Rocky Mountain Trench and its adjacent regions, the Rocky Mountains to the east and the Monashee Ranges of the Eastern Metamorphic Belt to the

FIG. 1: The epicentral region showing the provisional Seismological Service of Canada epicentre (SSC), the National Earthquake Information Service epicentre (NEIS) and our preferred epicentre (P). The seismic stations of the Mica array are shown as triangles.


53
Valemount
30 km
ROCKY MOUNTAINS
THO
P
SSC
NEIS
MONASHEE MOUNTAINS
DAI
CUM
MCV
SPR
52
119
117
TAB

west, have been considered to exhibit only low level seismicity. However it was not until 1963 that the Canadian Seismograph Network could located earthquakes of magnitude as low as 3 in this region (Milne et al., 1978). In recent years a number of seismic events have been located on the western margin of the Rockies i.e. the January 2, 1966 (M_L = 4.5) earthquake to the southeast of McNaughton Lake, the swarm events of 1973-74 (22 events $M_L \geq 3.0$), and most probably the February 4, 1918 earthquake (M = 5.6 - 6.1) north of station DAI (Rogers and Ellis, 1978). A study of this event should lead to an improved understanding of this seismicity and the propagation characteristics in this region. In particular a focal mechanism solution will provide information on the stress pattern.

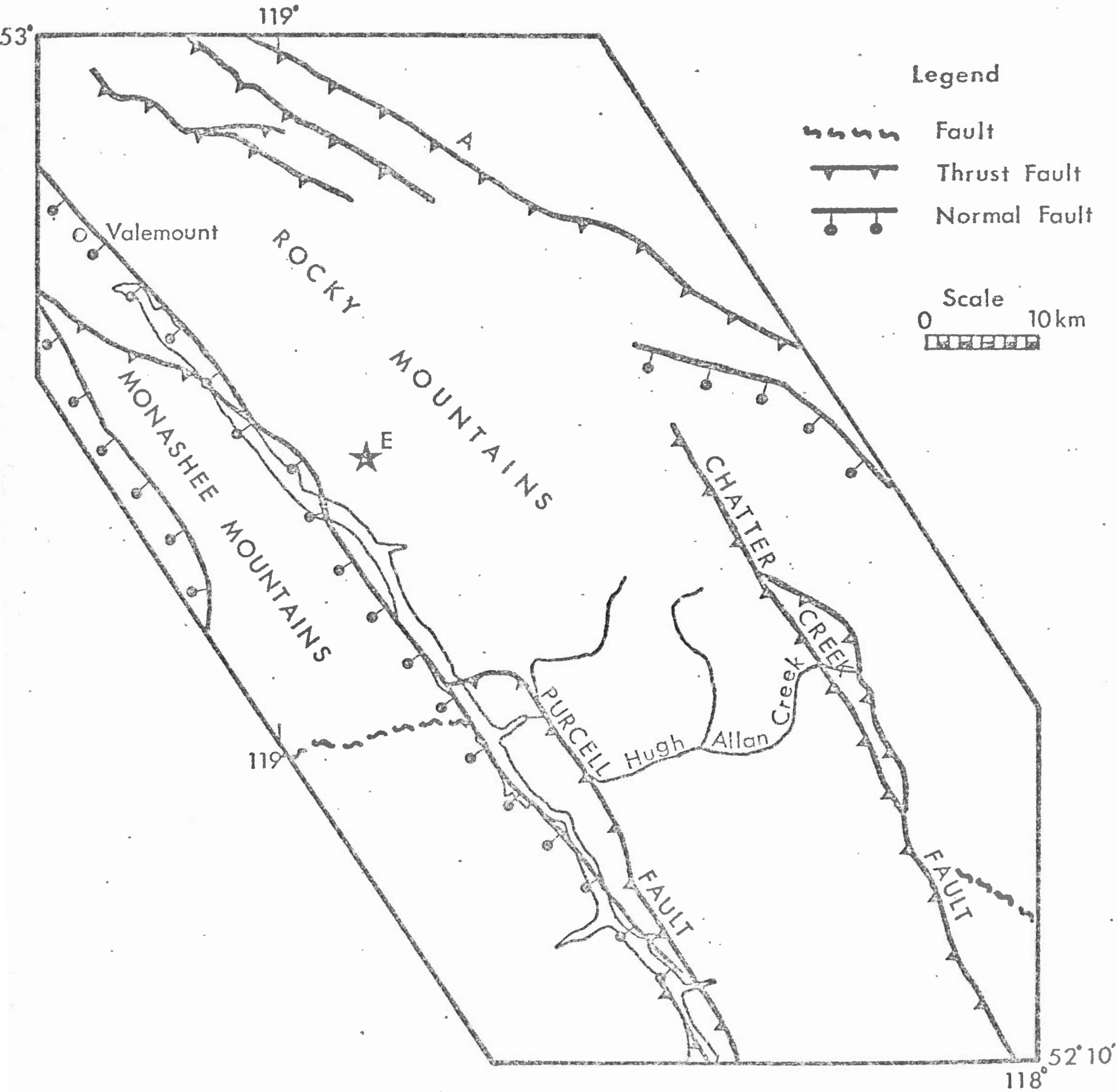
GEOLOGIC SETTING

To the northeast of McNaughton Lake which lies in the Rocky Mountain Trench (Fig. 2) are the Rocky Mountains, formed in several pulses of activity in the Mesozoic to Eocene by a series of low angle thrust sheets being stacked progressively eastward. In the region of the epicentre (E), the geology shows a westerly kink (Price and Mountjoy, 1970). This is evidenced in Fig. 2 by the more westerly direction of the fault designated A compared to that of the major thrust faults to the south, the Chatter Creek and Purcell Faults. Thus the epicentral region is one of relative complexity. Approximately 100 km to the south along the trench, the Rocky Mountain structure has been interpreted to show the Chatter Creek Fault dipping south-westward (Fig. 3) to a depth of about 13 km beneath the Rocky Mountain Trench (Douglas et al., 1969).

The Rocky Mountain Trench itself is a very enigmatic structure which has been interpreted by different authors as a half-graben, a transcurrent fault, a thrust fault structure, or a purely erosional feature. Speculation as to its origin frequently reflects Leech's (1965) suggestion that "the trench may mark an old, deep fracture zone that has reasserted itself through the allochthonous veneer". In the section of the trench adjacent to the epicentre, Price and Mountjoy (1970) have interpreted the faulting to be normal.

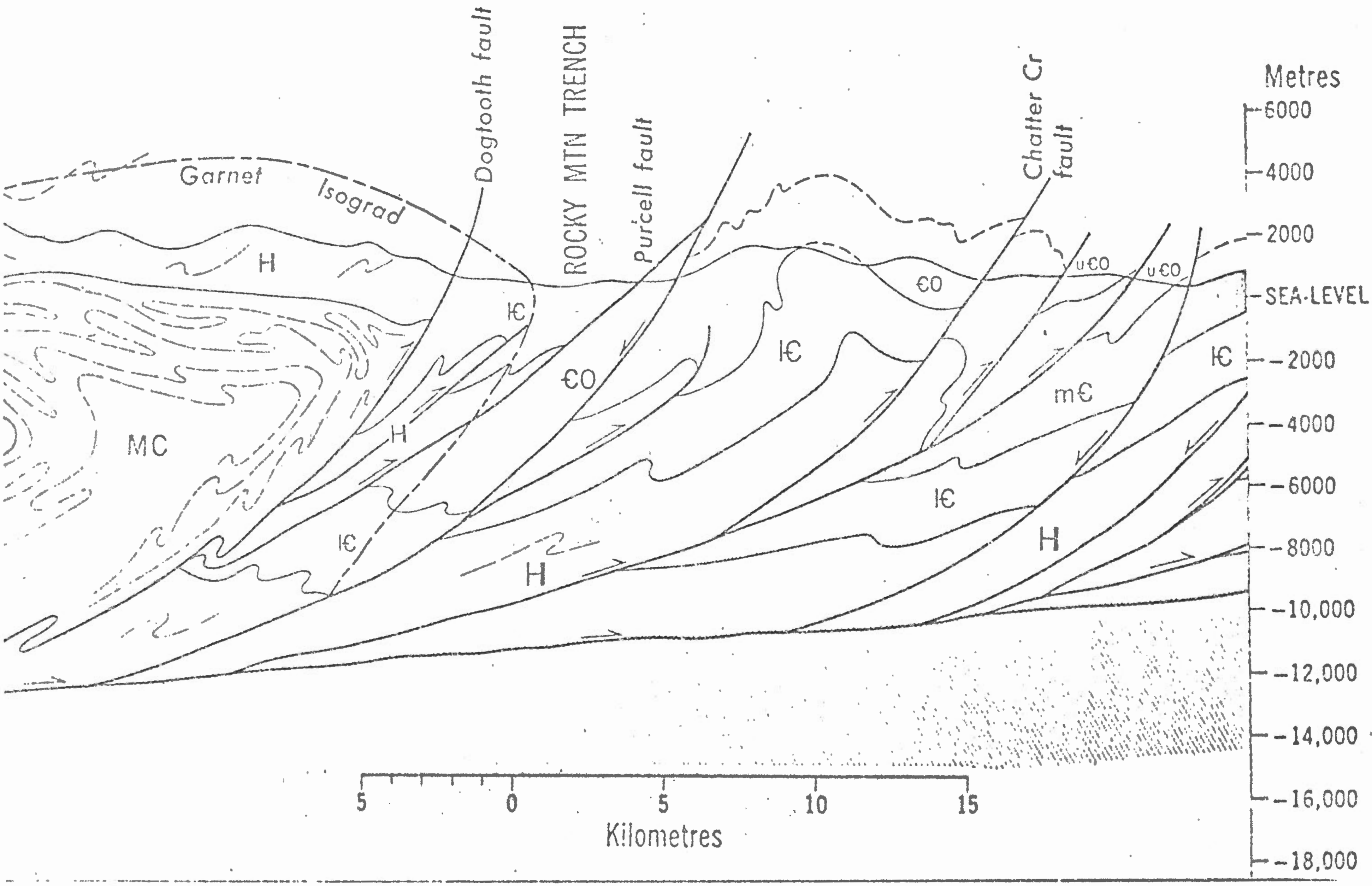
Flanking the trench to the southeast are the Monashee Mountains of the Eastern Metamorphic Belt which contain highly deformed structures but now appear tectonically quiescent.

FIG. 2: Outline of the northern section of McNaughton Lake and location of principal faults adjacent to the reservoir (from Price and Mountjoy, 1970; Ghent et al., 1977). The epicentre determined in this study is indicated by a star.



119°
53°
Legend
Fault
Thrust Fault
Normal Fault
Scale
0
10km
A
Valemount
ROCKY MOUNTAINS
MONASHEE MOUNTAINS
E
CHATTER CREEK FAULT
PURCELL FAULT
Hugh Allan Creek
119°
52°10'
118°

FIG. 3: Structure-section through the Rocky Mountain Trench near 51°30'. To the southwest of the trench (left) are the metamorphosed Precambrian rocks of the Eastern Metamorphic Belt, while to the northeast are the Cambrian Ordovician sedimentary rocks of the Rocky Mountain Thrust Belt. H = Hadrynian; MC = Precambrian or Paleozoic; C = Cambrian; CO = Cambrian and Ordovician; l = lower, m = middle, u = upper. (Reproduced from Douglas, 1969).


Garnet
Isograd
Dogtooth fault
ROCKY MTN TRENCH
Purcell fault
Chatter Cr fault
Metres
6000
4000
2000
SEA-LEVEL
-2000
-4000
-6000
-8000
-10,000
-12,000
-14,000
-16,000
-18,000
H
MC
lЄ
ЄO
uЄO
mЄ
5
0
5
10
15
Kilometres

HYPOCENTRE DETERMINATION

Prior to our study, provisional hypocentres had been reported by both the NEIS and the SSC (Fig. 1, Table 1). We note that although the epicentres are only separated by about 5 km the NEIS epicentre is in the Monashee Mountains while the SSC epicentre is along the Rocky Mountain Trench. Both organizations used readings at P_n and teleseismic distances with the SSC calculations also including arrivals from the Mica seismic array (Fig. 1). Due to significant variations in crustal structure and upper mantle velocity in this region (Berry and Forsyth, 1975; Clowes et al., 1978), one expects biases in these epicentres with the largest effects in the NEIS calculation as it is not constrained by the nearby array stations. Examination of the SSC calculations shows implausibly large travel time residuals at stations of the Mica network. For example, THO at a distance of approximately 17 km and travel time of less than 3 sec has a residual of -0.7 sec.

Stations of the Mica array are not well distributed to provide a high resolution location at the north end of McNaughton Lake. However because the stations in this array are so close to the epicentre it is likely that this array, possibly supplemented by data from Canadian Standard Seismic Network Stations EDM (380 km to the east) and FSJ (410 km west) will provide the best epicentre. To test whether readings from these additional stations should be used, the predicted and observed travel times at EDM for two well located events (March 4, 1973; June 12, 1977) near McNaughton Lake were examined. For the Canadian standard crustal model, residuals of 1 to 2 sec. were found. Therefore our preferred epicentre uses only data from the Mica array.

The signal amplitudes on the Mica array far exceeded the dynamic range of the system obscuring the S wave onset at all stations. Further, telemetry interference on the TAB channel was such that the P wave arrival could not be accurately timed. Therefore the initial hypocentre was based on only 5 arrivals. In an attempt to improve this epicentre, the aftershocks were examined. The 28 events for which a S arrival could be read at THO yielded a S-P time of 2.53 ± 0.15 s. As these events should be from the same volume of rock, this time difference was then used in the hypocentral solution for the main shock. This only moved the epicentre by 0.3 km but reduced the standard error of the focal depth from 2.5 km to 0.8 km. The epicentre is shown in Fig. 1 and the hypocentral parameters are given in Table 1. We note that this epicentre is approximately 5 km northeast of the SSC epicentre and into the Rocky Mountains. Provided the structural pattern at this latitude is similar to that further south (Fig. 3), the focal depth of 7.8 km is consistent with movement on one of the major thrust faults which outcrop to the east.

TABLE I

Hypocentres as determined for the May 14, 1978 earthquake. The RMS error of the time residuals and the standard errors of the epicentre and focal depth are shown in brackets.

Origin Time			Geographic Coordinates		Depth	Organization
h	m	s	Lat.	Long.	km	
22	37	03.8	52.57 N	118.89 W	19	NEIS*
22	37	03.1 (.6 s)	52.61 N	118.90 W (3.3 km)	7.1 (5.5 km)	SSC*
22	37	02.05 (.03 s)	52.65 N	118.87 W (0.3 km)	7.8 (0.3 km)	This study

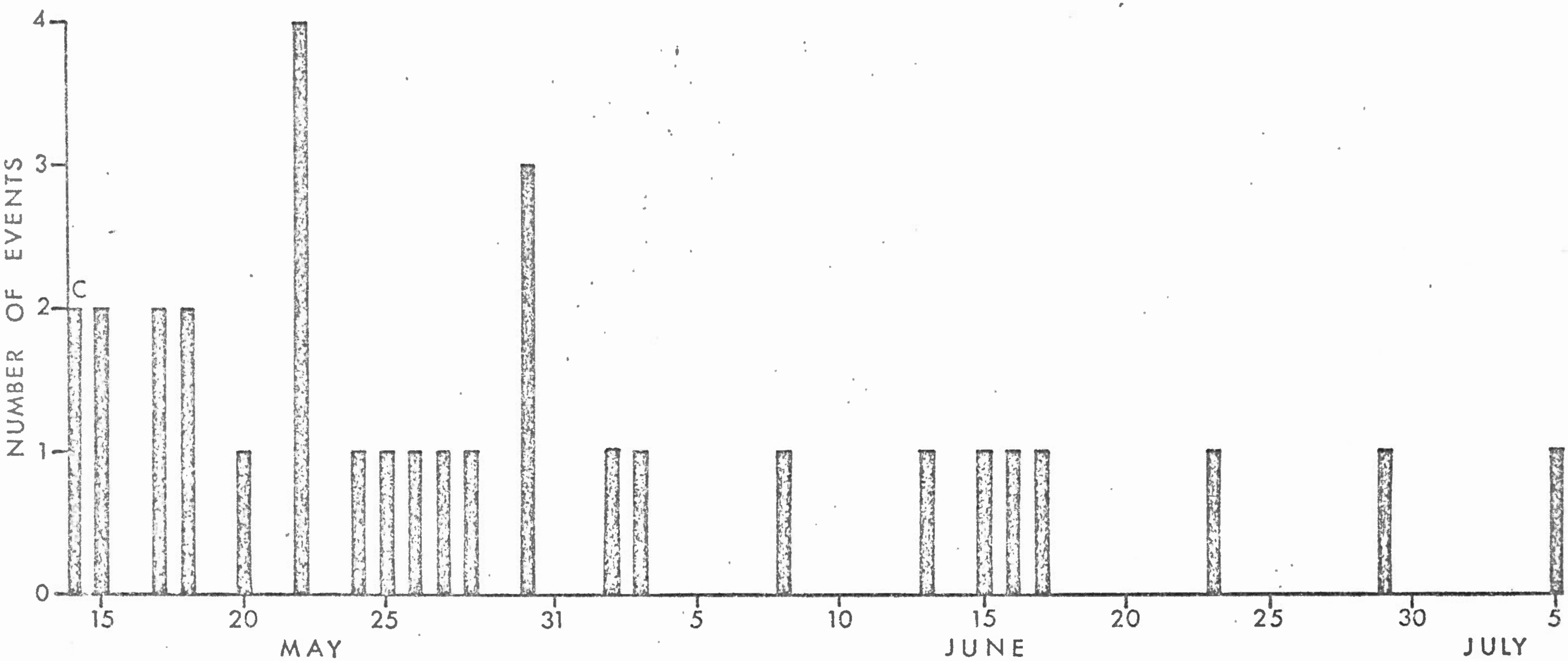
*The National Earthquake Information Service (NEIS) and Seismological Service of Canada (SSC) hypocentres are from provisional calculations.

FORESHOCK AND AFTERSHOCK INVESTIGATIONS

In normal operation of the Mica seismic array, the six seismic data channels plus WWVB time code are recorded on FM magnetic tape and one station, normally CUM, on a helicorder. Local events observed in the helicorder monitor station are played back from the magnetic tape onto charts to obtain timing and coda length for location and magnitude calculations respectively. Since initiation of array operation in December 1972 the seismicity near the northern end of the reservoir has been low (Ellis et al., 1976). The closest earthquake to that of the May 14 event was on August 28, 1973 of coda length magnitude $\hat{M}$ = 2.5 and located 20 km to the south in the Monashee Mountains. In the epicentral region any event of $M_L > 2$ would have been located.

Following the May 14 event the magnetic tapes for the previous ten days were searched in detail, with particular emphasis on the THO channel, and no foreshocks were observed. Following the earthquake, THO was continuously monitored on helicorder and all possible aftershocks were played back onto chart records. In the following 8 weeks 28 events occurred with S-P times at THO in the range 2.15 to 2.75 s and with very similar signal characteristics. Two additional earthquakes for which the S-P times could not be read are believed to be aftershocks based on their signal characteristics and location. The maximum coda length magnitude was $\hat{M}$ = 2.6. Thus the magnitude difference between the mainshock and the largest aftershock is 2.2. Since stations THO, DAI, CUM and TAB are almost in a straight line, accurate location of events depends on good picks at MCV or SPR. Unfortunately the noise level at MCV is very high and none of these events could be accurately timed. SPR is 130 km from the epicentre and hence the signal was of low amplitude and usually very emergent. As a result, although the S-P times and event characteristics indicate that they are from the same source region, only for 6 events were the calculated epicentres within 5 km of the mainshock. The standard errors of the epicentres were large. Fig. 4 shows the time distribution of these 30 events.

FIG. 4: Time distribution of earthquakes a THO from May 14 to July 10 with S-P times between 2.15 and 2.75 s and having a similar character.


NUMBER OF EVENTS
0
1
2
3
4
C
15
20
25
31
5
10
15
20
25
30
5
MAY
JUNE
JULY

FOCAL MECHANISM

The preliminary focal mechanism for this earthquake is shown in Figure 5. This is obtained by combining first motion data from the Eastern Washington and Puget Sound networks, the arrays at the Mica and Libby Dam reservoirs, the Newport Geophysical Observatory, and the Alaska regional tsunami warning system with data from the Canadian network. Some additional data may be obtained from WWNSS stations which have been ordered. The program used to compute the solution is that of Wickens (Wickens and Hodgson, 1967) with the P_n angle of emergence restricted to 60° and 50% weighting for first motions for which there could be a different interpretation.

The best solution allows right lateral strike-slip on a northwest fault plane with a significant thrust component or predominantly thrusting on a northeast fault plane with some left lateral strike-slip motion. Because the northwest striking plane approximates the strike of the Rocky Mountain trench and other features in the region and the dip is similar to that of the major thrust faults (Fig. 3) it is our preferred interpretation in this preliminary analysis. The pressure axis from the solution is at a low angle to the northeast, roughly perpendicular to the strike of the trench suggesting north-east horizontal compression is a likely cause of the earthquake.

The computer program produces two alternate but lower scoring solutions which are reproduced in Figure 6. One involves

FIG. 5: Best P nodal solution for May 14, 1978 earthquake. Projection is lower half of focal sphere; solid circles indicate compressions and open circles dilatations. Smaller circles indicate data of lower reliability. P is the pressure axis and T is the tension axis of the solution.

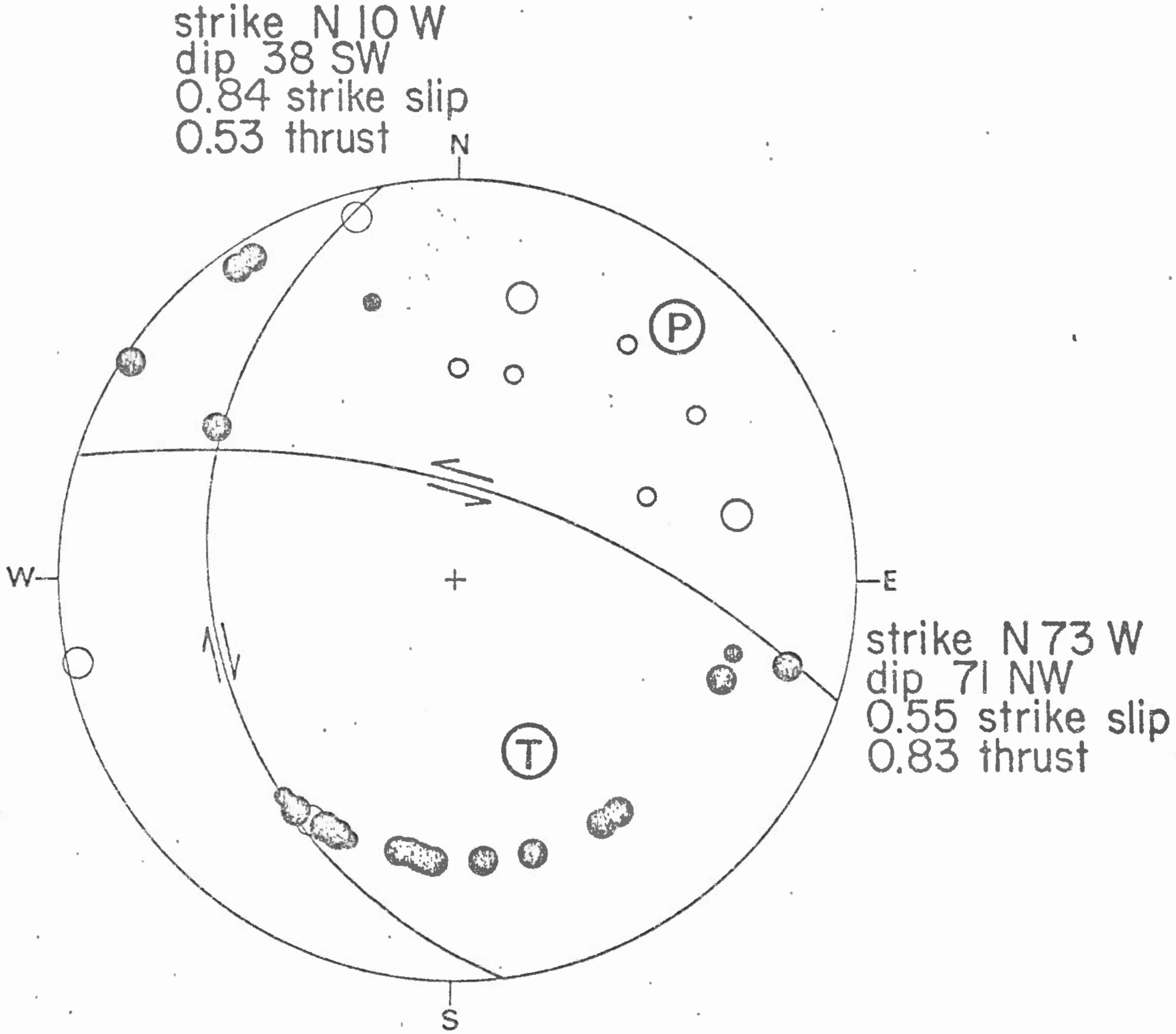
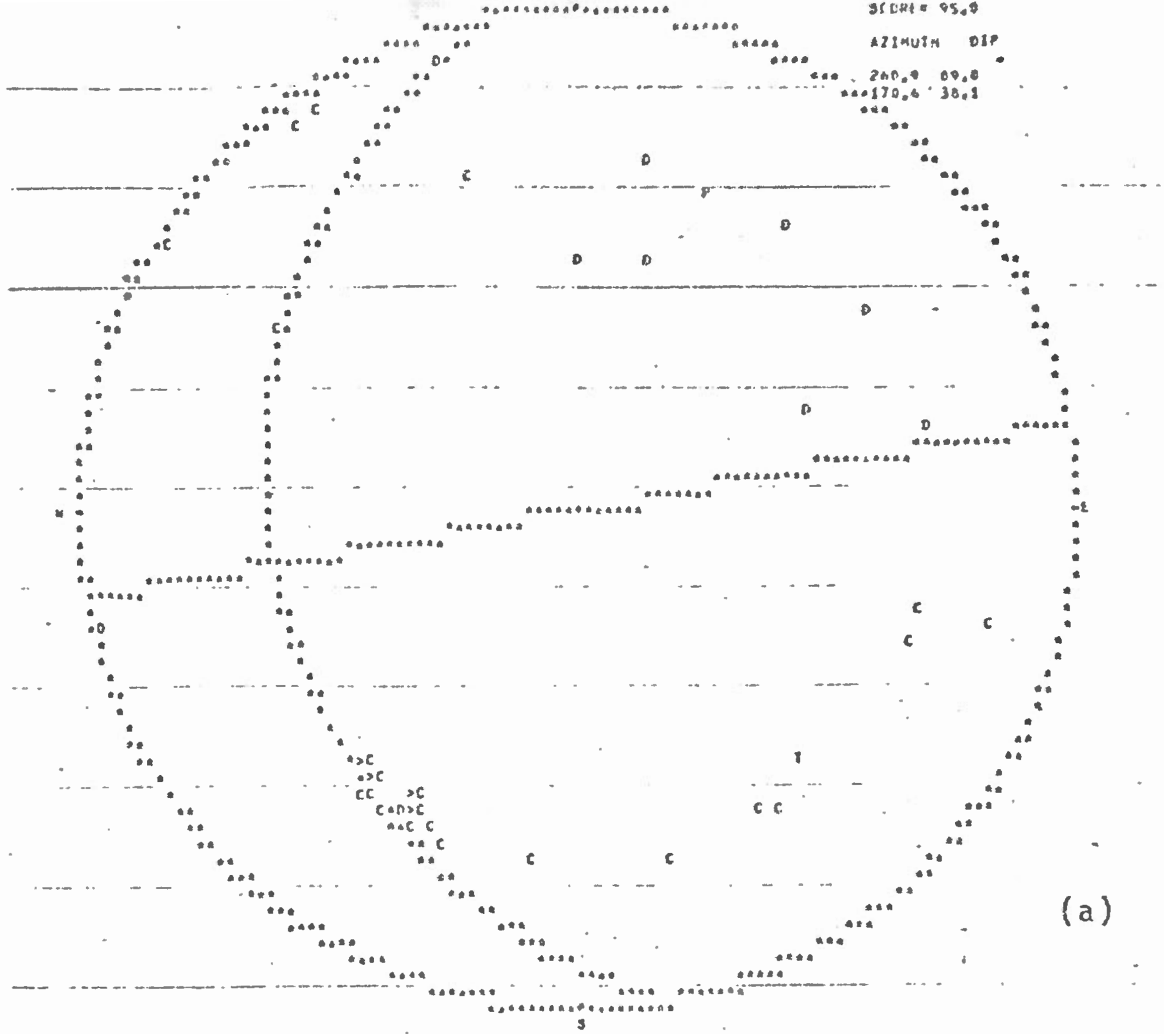
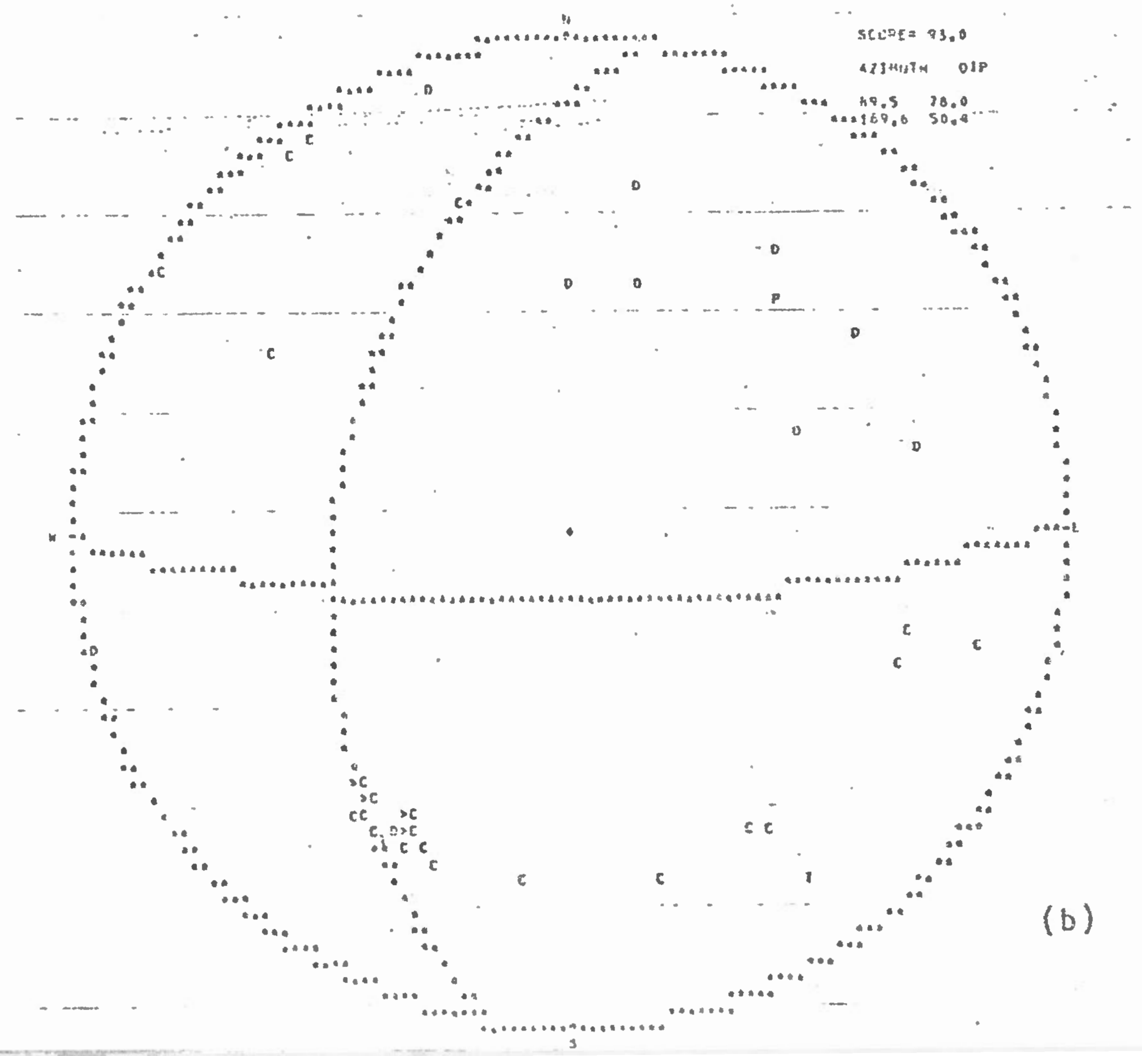

strike N 10 W
dip 38 SW
0.84 strike slip
0.53 thrust
N
W
E
S
P
T
strike N 73 W
dip 71 NW
0.55 strike slip
0.83 thrust

FIG. 6: Two alternate but lower scoring P nodal solutions possible with the same data set.


SCORE= 95.0
AZIMUTH DIP
260.0 69.8
170.6 38.1
E
S

(a)


N
SCORE= 93.0
AZIMUTH DIP
69.5 78.0
169.6 50.4
W
E
S

(b)

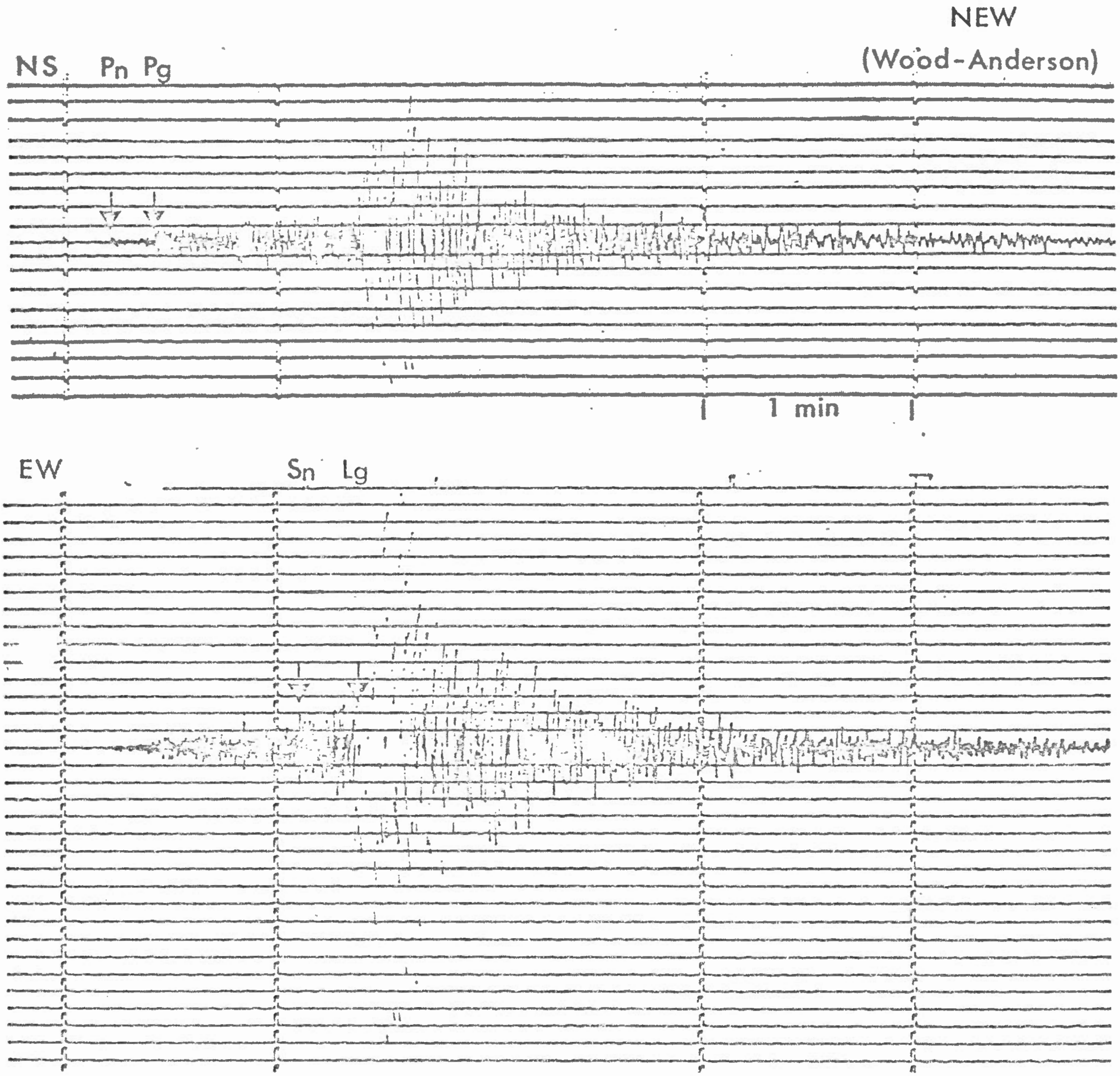
shifting of the rather poorly defined east-west fault plane. The other requires station MCV to be incorrect. The MCV arrival is implusive and a check on the polarities of teleseismic arrivals occurring shortly after this earthquake suggest the polarity of the instrument is correct. Thus this alternate solution seems unlikely.

Lg PROPAGATION

The seismogram at Newport Washington (NEW) shown in Figure 7 exhibits a well-developed Lg phase (a guided wave in the crust whose velocity is essentially the same as the Sg phase.) The large amplitude on the transverse (EW) component at NEW, the monotonic frequency content and the slow attenuation rate are distinctive properties of the Lg phase (e.g. Press and Ewing, 1952). This phase propagates well in eastern North America which probably reflects a certain uniformity in the velocity structure of the crust, thus providing an efficient wave guide. This mode of wave propagation is normally not observed in the cordillera, probably because most local earthquakes are near the coast and propagation paths are across the strike of the mountains where the crustal structure is extremely variable (Berry and Forsyth, 1975). However, for this event Lg propagates well to the south. This effect was first noticed in seismograms of the February 4, 1918 earthquake (Rogers and Ellis, 1978) and can be seen on the seismograms of at least one more recent event in the same epicentral region (June 12, 1977).

The large S to P amplitude ratio at NEW is undoubtedly partially due to focal mechanism as crustal waves to NEW leave the focal region (see Figure 5) near a nodal plane in P amplitude, which will be a S maximum. However, the distinctive Lg character of the S arrival suggests that there is a basic difference in the crustal structure which allows propagation to the south but not to the west.

FIG. 7: Seismograms of May 14, 1978 earthquake as recorded on visual seismograph with Wood-Anderson response at Newport, Washington. Note large S to P amplitude ratio, especially on EW component.


NEW
(Wood-Anderson)
NS
Pn
Pg
1 min
EW
Sn
Lg

This means that the m_{bLg} magnitude scale should be used in place of the M_L scale for certain epicentre - station combinations and that eastern North America attenuation laws (e.g. Milne and Davenport, 1969; Nuttli, 1973) may be more appropriate for seismic risk assessment. Practically, for these cases the net effect is an increase of amplitude and energy which is predominantly delivered at one frequency. The properties of this propagation will be investigated in more detail as more seismograms to the south of the epicentre become available.

INTENSITY

The isoseismal map is shown in Figure 8. The sparseness of the population in the region precludes exact positioning of the isoseismals but the felt area is defined by the outer dashed line in Figure 6 is approximately 50,000 square kilometers. This felt area is greater than that expected for an earthquake of magnitude (M_L) 4.8 in western North America. This is likely due to the efficient propagation of the Lg phase. The attenuation of intensity with distance approaches the empirical relationship for eastern North America of Milne and Davenport (1969). Figure 9 shows the intensity values and the intensity attenuation curves of Milne and Davenport (1969) for eastern and western North America.

FIG. 8: Isoseismal map of May 14, 1978 earthquake. Note the distance the earthquake was felt to the south. Empirical relationship for maximum felt distance for California (Gutenberg and Richter, 1956), often used for western Canada, suggest maximum felt distance for a M_L = 4.8 earthquake should be about 100 kilometers.

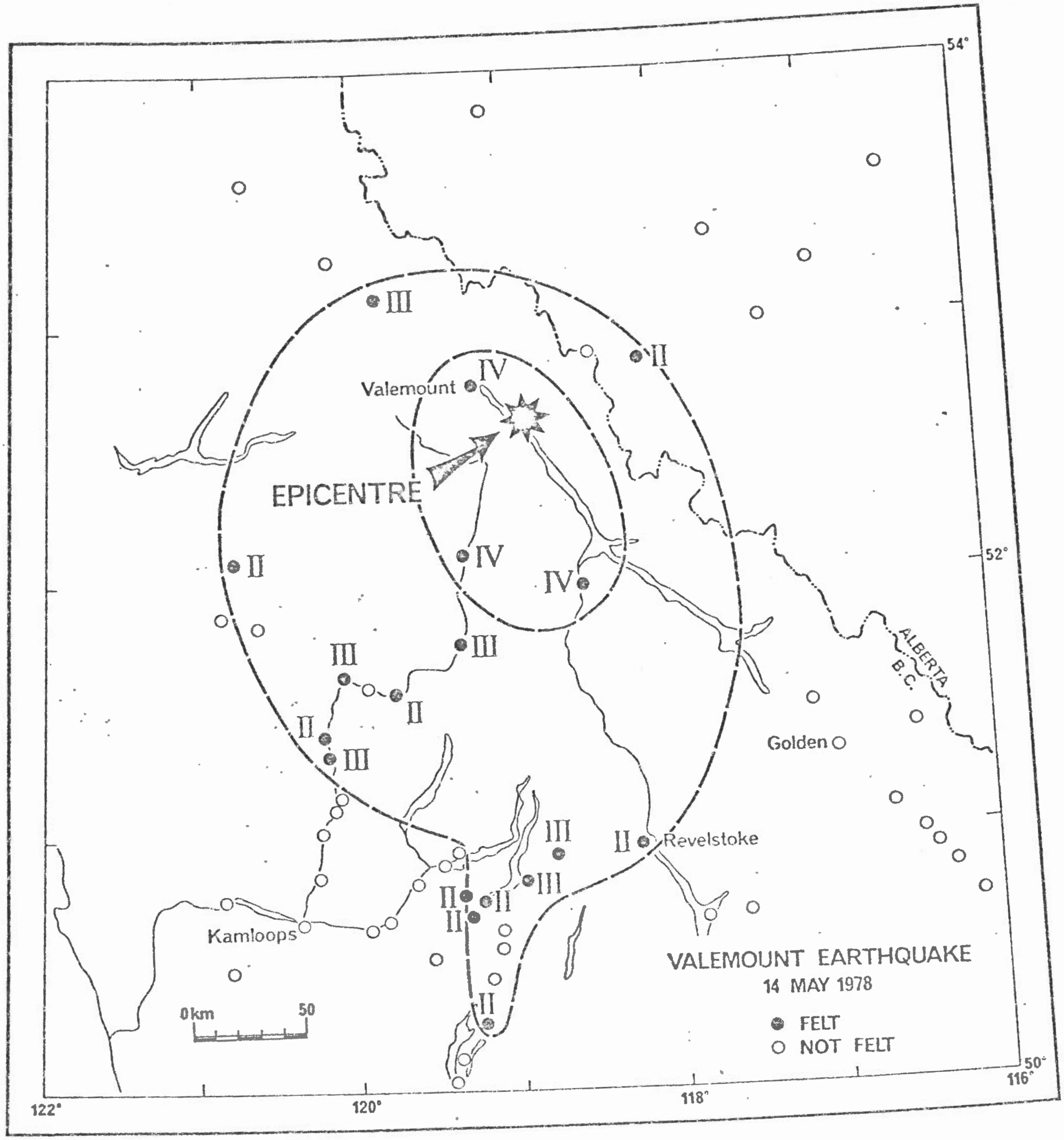
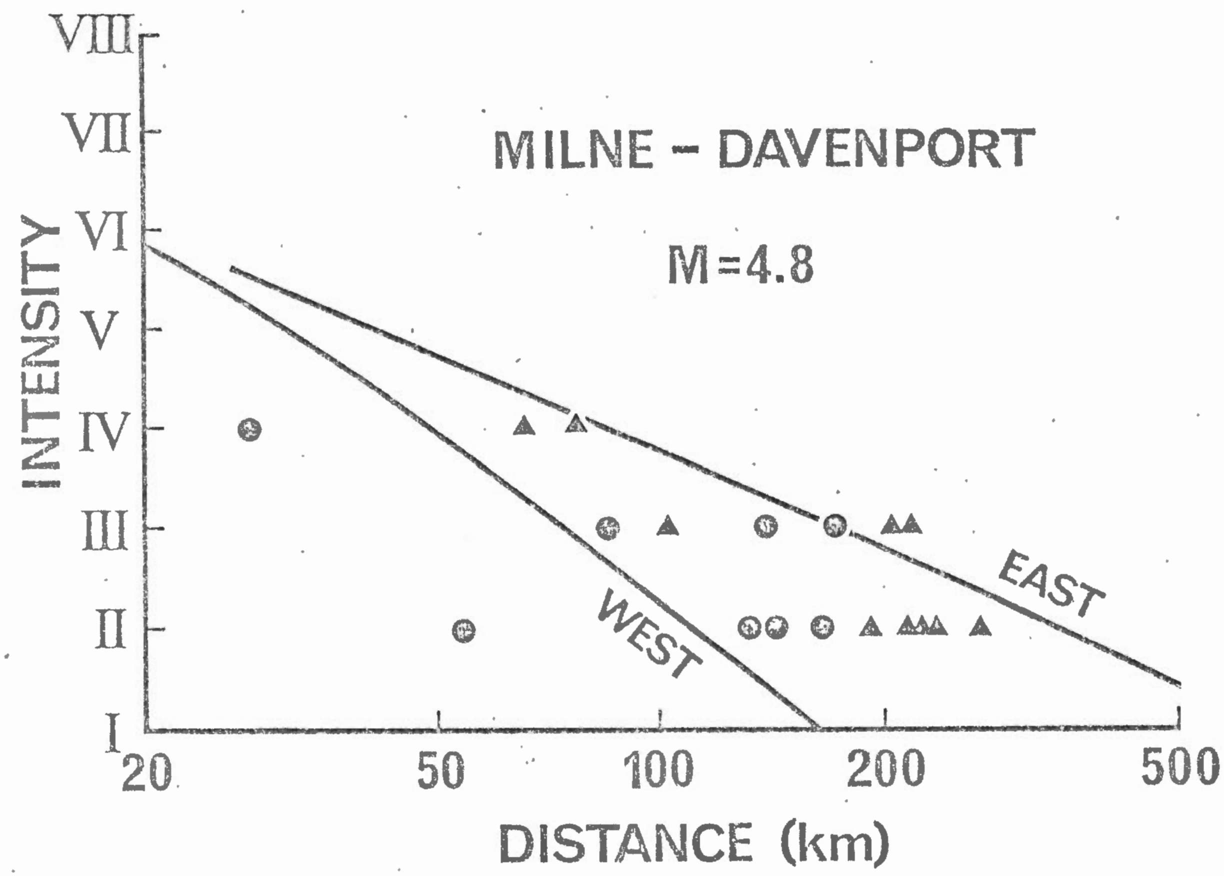

EPICENTRE
Valemount
Kamloops
Revelstoke
Golden
ALBERTA
B.C.
VALEMOUNT EARTHQUAKE
14 MAY 1978
FELT
NOT FELT
0 km
50
122°
120°
118°
116°
54°
52°
50°
IV
III
II

FIG. 9: Intensity values and the intensity attenuation curves of Milne and Davenport (1969) for eastern and western North America. Dots indicate sites in approximately an east-west direction from the epi-centre and triangles indicate sites in approximately a north-south direction.



MILNE - DAVENPORT
M=4.8
INTENSITY
VIII
VII
VI
V
IV
III
II
I
20
50
100
200
500
DISTANCE (km)
WEST
EAST

RELATIONSHIP OF EARTHQUAKE TO McNAUGHTON LAKE

Two recent publications have summarized the relationship of seismicity changes to reservoir loading (Gupta and Rastogi, 1976; Simpson, 1976). Although the list of cases where the seismic regime has been modified by reservoir inpounding now exceeds thirty, the most significant data have been derived from the seven cases where earthquakes of magnitude 5 or greater have occurred. Several important characteristics of reservoir induced seismicity are found.

(1) The large earthquakes have been associated with a long series of foreshocks and aftershocks.

(2) In most cases the activity has started soon after inpounding and the largest shocks have occurred near the time of highest water level.

(3) For the reservoirs with the largest earthquakes, the magnitude M_1 of the largest aftershock is related to the M_o of the mainshock by $M_o - M_1 = 0.6$. For non-reservoir shallow earthquakes, Båth (1965) found $M_o - M_1 = 1.2$.

(4) The focal mechanism solutions are of the strike-slip or normal type.

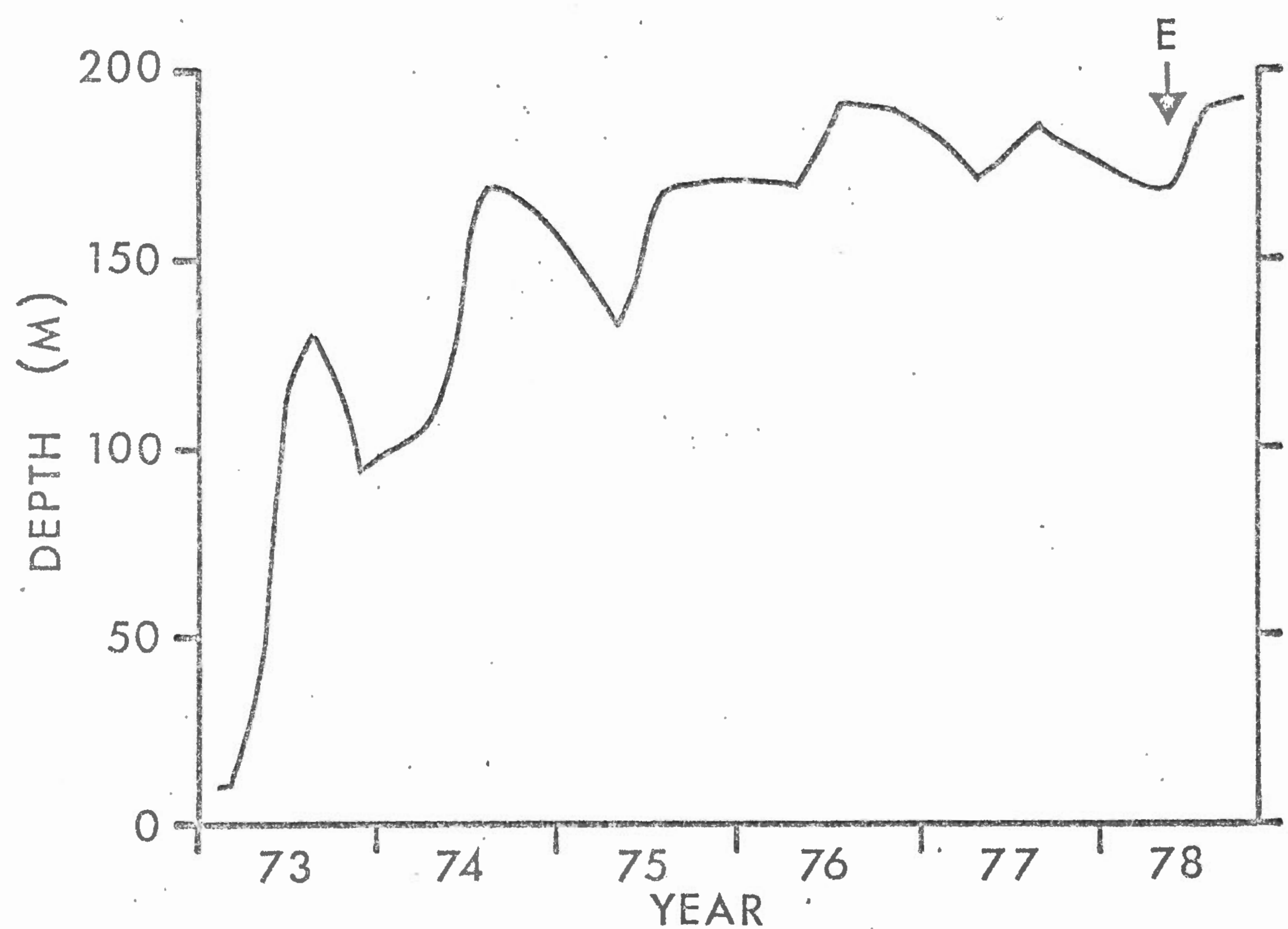
(5) Activity is most common in reservoirs greater than 100 m deep.

(6) For both foreshocks and aftershocks, the b-value in the frequency magnitude relationship is greater than 1 for the larger earthquakes.

The data for this earthquake are not consistent with the first five characteristics. With respect to (6), b-values have not as yet been determined. Specifically, no foreshocks were observed for this earthquake; this, the first seismic activity did not occur until after four years of impounding; and was near a seasonal load minimum (Fig. 10). Further, $M_o - M_l \approx 2$, i.e. more characteristic of non-reservoir earthquakes, and the focal mechanism solution has a significant thrust component. Although the maximum depth of McNaughton Lake is 190 m (Fig. 10), this occurs 80 km from the epicentre. The maximum depth of adjacent portions of reservoir varies seasonally between 35 and 55 m. Only at the Marathon reservoir in Greece has an earthquake of comparable magnitude been associated with such shallow water depths. On the basis of this evidence, it is unlikely that this earthquake is related to filling of McNaughton Lake.

Before completely dismissing the possibility of a relation between the earthquake and reservoir, the observations that the earthquake occurred near a load minimum and that there was a significant thrust component should be considered jointly. Calculations by Snow (1972) show that for thrust environment, lowering of the reservoir level moves the system towards instability. The stability producing load has been removed but the increase in pore pressure remains as the time lag for change of pore pressure at depths of several kilometers is of the order of months. These observations would therefore appear to be consistent with induced seismicity in a thrust environment. However, in view of the other evidence, this relationship appears unlikely.

FIG. 10: Maximum water depth in McNaughton Lake. The May 14, 1978 earthquake occurred near a seasonal minimum. Time of occurrence of this earthquake is indicated by the arrow.


E
200
150
100
50
0
DEPTH (M)
73
74
75
76
77
78
YEAR

DISCUSSION AND CONCLUSIONS

1) The epicentre of the earthquake was near 52.65°N and 118.87°W, approximately 30 kilometers southeast of Valemount, B.C. on the northeast side of the Rocky Mountain Trench, which at this point contains the Mica Reservoir (McNaughton Lake). The focal depth was near 8 kilometers.

2) The most likely interpretation of the preliminary focal mechanism solution suggests right lateral strike-slip motion on a north-west striking low angle fault with a significant thrust component. The pressure axis of the focal mechanism solution is orientated at a shallow angle in a northeast direction, consistent with the forces that formed the imbricate structure of the Rocky Mountain in this region.

3) The lack of previous post reservoir filling seismicity in the immediate epicentral area, the lack of foreshocks, the large difference between the mainshock and the largest aftershock, the shallow water depth, and the significant thrust component in the preliminary focal mechanism solution, mitigate against this being a reservoir induced earthquake.

4) The isoseismals are elongated to the south and the distance to which the earthquake was felt in this direction approaches the intensity versus distance relationships for eastern North America. The preliminary focal mechanism solution predicts a maximum on the S wave radiation pattern in this direction and the seismograms at Newport Washington suggest efficient propagation of S energy as a Lg phase, which is not commonly observed in the Cordillera.

ACKNOWLEDGMENTS

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