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The 1956 June 03 arctic margin earthquake off Borden Island, Northwest Territories

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THE 1956 JUNE 03 ARCTIC MARGIN EARTHQUAKE OFF BORDEN ISLAND

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ABSTRACT

The earthquake of 3 June 1956 on the Arctic margin of Canada, northwest of Borden Island, has been briefly studied during a reappraisal of instrumental data of some Canadian earthquakes. The revised parameters are: latitude 79.83°N±0.20°, longitude 116.99°W±1.0°, crustal depth (18±18 km), H = 05h 19m 26.6s U.T., and magnitude m_b 5.7, M_S 5.4. The epicentre is unlikely to be more accurate than ±20 km. This is the second largest earthquake known from the Arctic margin of Canada.

RÉSUMÉ

Le tremblement de terre du 3 juin 1956, qui s'est produit sur la marge arctique du Canada, au nord-ouest de l'île Borden, fut brièvement étudié au cours d'un réexamen des données instrumentales de quelques tremblements de terre canadiens. Les paramètres modifiés sont les suivants: latitude 79.83°N±0.20°, longitude 116.99°O±1.0°, profondeur dans la croûte (18±18 km), H = 05h 19m 26.6s T.U., et magnitude m_b 5.7, M_S 5.4. Il est peu probable que l'épicentre soit plus exact que ±20 km. Ce séisme est le deuxième en magnitude parmi ceux connus le long de la marge arctique canadienne.

INTRODUCTION

During a project to relocate all early instrumental earthquakes in Canada east of the Cordillera, a few of the more significant earthquakes have been thought worthy of some extra attention. For the earthquake of 1956 in the Arctic Ocean (Fig. 1), this extra interest was piqued by how low the magnitude in the Canadian Earthquake Epicentre File (CEEF), 5.0, was relative to the size of the earthquake implied by the two pages of entries in the International Seismological Summary (1963; henceforth referred to as ISS). The CEEF epicentre was adopted from the U. S. Coast and Geodetic Survey (USCGS) epicentre, and was not subsequently revised.

To compile this report we examined all the records from the Canadian seismographs. In addition to the records mentioned below, we saw the HBC (Horseshoe Bay, B.C.) and ALB (Alberni, B.C.) records, which had no usable information, and neither BAN (Banff, AB) nor KNOBQ (Knob Lake, P.Q.; the predecessor to the SCH seismograph at Schefferville, P.Q.) produced a record for this day. Past large Arctic margin earthquakes include four in the Beaufort Sea in 1920 (M≈6.5), 1937 (M≈5.5) 1975 (m_b5.1) and 1986 (m_b5.0), and one off Cape Prince Alfred in 1987 (m_b5.5) (Fig. 2).

EPICENTRE

The Seismological Bulletin (1956b, p. 69) gives Canadian readings for the earthquake, with the epicentre of $79\frac{1}{2}$°N $118\frac{1}{2}$°W, attributed to the USCGS. This epicentre was also adopted by the CEEF. Only U.S. stations were used to compute the USCGS epicentre. Although they included the close stations COL, SIT, BUT, and BOZ, all the stations lie within the azimuthal quadrant to the south of the epicentre. The Bureau Central International de Séismologie (BCIS, 1956) computed the epicentre as 80°N 118°W, H=05:19:22.

The ISS determined an epicentre of 79.9°N 117.8°W, primarily from P-wave readings made at the 123 world-wide stations that reported to ISS (Appendix A). These included all the stations used in the USCGS epicentre and most of those in the BCIS (the microfiche is of too poor quality to reproduce). The ISS solution has rather large residuals for the closest stations (RES P –5 s, S –13 s; COL: P –3 s, S –12 s; SCO: S +10 s), reflecting the compromise necessary to fit the majority of distant stations. Sykes (1965) redetermined epicentres for many Arctic earthquakes using Jeffreys-Bullen 1958 travel times. His solution 79.91° N, 117.70° W, H=05:19:23.2 had a standard error of 1.46 s, and is essentially identical to the ISS solution.

On the author's request Dr. R. G. North recomputed a teleseismic epicentre starting with the same stations and P-arrival data as ISS but using modern travel times. This gave 79.85°N 117.32°W H=05:19:27.8 for a 33 km depth, with a standard error of 3.1 s. The epicentre is very similar to the ISS, and it also has comparable residuals on RES and COL (RES P –5 s, S –9 s; COL: P –4 s, S –10 s). Relative to the closeness of the BCIS, ISS, and North epicentres, the USCGS epicentre is distinctly farther to the southwest.

We checked the time correction on the RES record and consider it good to 1 s or so, despite the clock drifting about 19 s per day, so the teleseismic residuals on RES are not due to poor timing.

The simplest alternative way to interpret the residuals on the closest stations is that there might be a local, high velocity region in the upper mantle of the region. For RES, over the ≈800 km path the velocity would have to be 5% faster than the standard Canadian model (viz. 8.6 rather than 8.2 km/s for Pn) and for COL the path velocity over the ≈1900 km would have to be 2% faster than the model. Such large deviations have been proposed before (but not confirmed). Qamar (1974) suggested a P-wave velocity of 8.5 km/s for the upper mantle in the Baffin region from a similar discrepancy between local and teleseismic arrivals, though data on Figure 5 of Hasegawa et al., (1979) suggests the upper mantle velocity under the western Arctic might be less than the assumed 8.2 km/s.

However the current model for locating Canadian earthquakes in the Arctic does not incorporate such higher or regionally-varying velocities, so that for consistency with current epicentres (mostly of small earthquakes located using the Pn and Sn phases) the following approach is preferred.

As an alternative to the ISS epicentre, we used P arrivals at an azimuthally-balanced set of close stations (RES, COL, SCO and TIK) together with the Sn phases at RES and COL (Appendix B), the standard earth model for Canadian earthquakes (Crustal thickness = 36 km, P_{crust}=6.2 km/s, S_{crust}=3.62 km/s, P_{mantle}=8.2 km/s, S_{mantle}=4.7 km/s, Teleseismic P by Herrin, Teleseismic S as Sn), and a fixed depth of 18 km to get 79.83°N 116.99°W H=05:19:26.6 as our preferred epicentre.

Two other epicentres were located: without using the COL S; and without using either the RES or COL S phase (Fig. 3). These epicentres lie to the southwest of all but the USCGS epicentre and each fits the RES S well but misfits the COL S by 5 s.

Our preferred epicentre (Fig. 3) lies 50 km northeast of the CEEF/USCGS epicentre and 17 km southeast from the ISS epicentre (i.e. closer to land and to RES, as is to be expected from fitting its phases with the standard mantle velocities). It reflects the greater weight we gave to fitting the phases misfit by the ISS solution, including the RES phases, which are also those currently important for locating smaller earthquakes in the region.

We conclude from the the above that the adopted epicentre is **1)** unlikely to be accurate to better than ±20 km (based on the scatter of the epicentres on Fig. 3), **2)** preferable to the USCGS epicentre (as are the preceding ISS and BCIS epicentres), and **3)** an improvement relative to other offshore epicentres in the vicinity (most of which were located using RES together with MBC, ALE, and INK).

As relocated, the epicentre lies 165 km NNW from Borden Island, the nearest land, and beneath about 1500 m of water.

MAGNITUDE

Original Assessments

No magnitude is given by USCGS or ISS, and unfortunately neither catalogue listed amplitude and period data that would allow calculation of m_b or M_S. The BCIS gives only "Magn. 5 (Moskva)". Sykes (1965) determined a magnitude (inferred to be M_S, after Richter, 1958, p. 348) of 4.9 from two stations. The 1990 version of the CEEF gives the magnitude of the earthquake as M_L 5.0. Unlike many similar-sized earthquakes this earthquake was not re-evaluated by Basham et al. (1982). On examination, the CEEF magnitude was found to have been taken from the Dominion Observatory epicentre cards (Fig. 4), on which Smith had written "max 23 mm @ 12.0 sec on the LPEW Spreng." against the Resolute entry and "The magnitude is doubtful because the curve of this instrument differs so greatly from the general shape of a standard W.A. (Wood-Anderson) calibration curve. The shock is probably at least a M = 6" on the bottom of the card. From examination of the original records RES we also read an amplitude of 23 mm at a period of 12 s on LP Sprengnether E-W component. This instrument was calibrated in December 1957 (Seismological Bulletin, 1957) and had a magnification of 1200 at 12 s. This period is very different from the periods used for present-day M_L or m_N calculation.

As a side-note, the surface waves from the 1956 earthquake were studied by Brune and Dorman (1963) to determine wave propagation properties and crustal structure of the Canadian Shield.

EPRI assessment

Two estimates of magnitude were cited in a study funded by the Electric Power Research Institute (EPRI, 1989). The EPRI report quotes Smith's M_L 5.0 and appeared to have deduced a magnitude 5.3 (scale unspecified, but presumably an equivalent of M_S) from the plotting symbol of the earthquake on a map of Arctic seismicity given by Rothé (1969). EPRI's final assigned moment magnitude was 5.49 (based probably on a conversion from Gutenberg and Richter's 'class d') and quality code C2, which implies a poor determination with an estimated uncertainty of ±0.40 magnitude units.

Magnitude from number of stations reporting to ISS

From the number of stations reporting to ISS (#ISS=123) as a fraction of the maximum number reporting for a single event (N_M = 340 for 1956) and EPRI's graphical relationship for *North American* earthquakes (see Fig. 5) we deduced a moment magnitude ($M_{\#ISS}$) of 5.9. While EPRI (1989) report this is a useful method where other data are lacking, we note that the visual scatter in the data relative to the average line is certainly not less than $\pm\frac{1}{4}$ magnitude unit, and might be as much as $\pm\frac{1}{2}$ magnitude unit. Some conservatism is involved, however, in treating this remote Arctic event like a central United States earthquake, so that we conclude it seems unlikely to have been less than **M** $5\frac{1}{2}$.

M_S (Marshall-Basham)

The Canadian records of this earthquake have now been repatriated from Lamont-Doherty Geological Observatory in New York to Ottawa and we have read amplitudes and periods from the four operating LPZ components: HAL, OTT, RES, and VIC (Table 2). Because the periods are significantly less than 20 s, we have applied the corrections established by Marshall and Basham (1972) to correct the magnitude to an equivalent 20-s M_S. On the advice of colleagues, we have adopted the "continental N. America" path corrections, P(T), from Table 2 of Marshall and Basham (1972) as the most appropriate, despite the fact that the near-source path likely involves oceanic or thinned-continental crust. This set of corrections is also the most conservative of the four sets, ensuring that the magnitude is a reliable minimum.

Of the four readings (stations SFA and SAS did not operate vertical sensors), RES gives a minimum value because the the trace faded after the maximum readable amplitude. However, judged by relative amplitudes to the horizontal components (which did not fade) the measured amplitude is thought to be about half the actual, so the magnitude may be low by 0.3 units. The calibration for the HAL LPZ Benioff is not available, so the magnification used was taken from the shape of a standard curve (Willmore, 1959) adjusted so that it has the magnification of 2300 at 1 s stated in Seismological Bulletin (1957). This gives a corrected magnitude of 5.03, which seems too low compared to RES and VIC.

The OTT reading is good but the calibration of the instrument is not well documented. The calibration curve published in 1957 (Seismological Bulletin, 1957) refers to a record made with a 1 s seismometer and a 75 s galvanometer; in 1956 a 20 s galvanometer was used and the magnification was reported only at 1 s (Seismological Bulletin, 1956a). Tests of varying galvanometer damping suggest that the 1956 instrument may have had a velocity sensitivity at 12 s in the range 8000 to 11500, for a magnification in the range 4330 to 6230, which gives about 1 unit too small for the magnitude (though this magnification is qualitatively consistent with the peak on the Milne-Shaw horizontals relative to the Benioff LPZ).

If we ignore the HAL and OTT readings because of the uncertainty in the calibration, and add 0.3 units to the RES magnitude, the average magnitude is M_S 5.4 and the adopted magnitude should be taken as M_S 5.4 ± 0.3, or perhaps an even larger uncertainty.

M_S (Prague) (original)

For comparison we calculated M_S according to the "Prague formula" of Vanek et al. (1962) from the root-mean-square (RMS) ground amplitudes on pairs of horizontal components at HAL, OTT, SAS, RES, and VIC and from the single component (to give a minimum) at SFA (Table 3). The "Prague formula" is seldom used today as it was originally intended. However, it is one of the few magnitude formulas that use horizontal amplitudes, and so enables us to use data from SAS and SFA. The OTT and HAL values are taken from instruments for which the calibration is believed to be correct. The SAS seismometers are not on bedrock, and so the magnitude of 6.15

computed is probably too large because of site amplification. The average value (ignoring the RES reading which is at too close a distance, see Marshall and Basham, 1972, p. 435) is 5.8. Because the periods are much shorter than 20 s, it is likely that this value is higher than would have been derived from a narrow band, 20-s seismograph.

M_{SZ} (NEIS) Common usage today applies the "Prague formula" to amplitudes from vertical long-period instruments to give M_{SZ} as used by NEIS. This is sometimes written M_S. To avoid the need for corrections like those devised by Marshall and Basham, the NEIS restricts the periods to 18–22 s. Since the vertical amplitudes are typically 60-80% of the horizontal, these magnitudes may be 0.1 – 0.2 magnitude units smaller than would be computed from the original "Prague formula". All of the Canadian records are at too short a period.

m_b magnitude

Amplitude and period measurements were made on the VIC, SFA, OTT, and HAL vertical components for calculating the m_b (Table 4). Following Canadian practice, the amplitude measured was the largest in the first minute. Although amplitudes were measured from the OTT LP Benioff, there is some uncertainty in the magnification as discussed above as no calibration curve was published. However, the uncertainty is considerably less than for the long periods because the Seismological Bulletin (1956a) reports the magnification at 1 s, close to the period of the reading. The magnitudes computed from the two components are very similar, but nevertheless we prefer the Benioff SP reading. The magnification for SFA is given as "ca. 50,000 at 1 s" in the Seismological Bulletin (1956a), and the calibration in the Seismological Bulletin (1959) notes "In addition to the instruments for which curves are shown, a Benioff short-period vertical seismometer is operating but the sensitivity has been altered from time to time so that no magnification curve is available". For these reasons we have not included the computed magnitude in the average. The magnification would have to have been ca. 10,000 for the computed magnitude to have been as large as the adopted average. Periods ranged from 0.6 to 1.3 s and computed m_b's from 4.98 to 5.86, for an adopted average of m_b=5.7.

Conclusions

Although M_S 5.4 is a large increase on the CEEF M_L 5.0, it still seems low relative to the number of stations reporting to the ISS, which gives **M** 5.9. However, recalling that the majority of reporting stations reported P-waves, it may be that the m_b of 5.7 was large relative to the M_S, (as is determined from the few Canadian stations), so accounting for the large number of phases reported to the ISS. When the various values are considered, three different magnitude scales ($M_{\#ISS}$, M_S (Marshall-Basham), and m_b) give 5.7±0.3 for the magnitude of the 1956 Arctic Margin earthquake.

DEPTH

The depth of the 1956 earthquake is unknown, and so is taken as crustal (18±18 km) following standard Canadian practice. The general consistency of M_S and m_b magnitudes suggests a crustal rather than sub-crustal focus (compare Hasegawa et al. 1979, p. 823).

When the Canadian records were re-read, phases (given below in terms of their lag behind the P phase) were noted that might correspond to the depth phases pP and sP:

HAL	P+3.8 s, P+6.2 s
OTT	P+4.4 s, P+6.4 s
VIC	P+3.2 s, P+5.7 s

If these and a secondary phase at station CRT (at P+7 s identified by the ISS as pP) are indeed depth phases, they are reasonably consistent with a depth of 13 ± 3 km, with the CRT phase then being sP. Along the Arctic Margin, only the depth of the 1975 Beaufort Sea earthquake (40 km) is known (Hasegawa et al., 1979). Therefore we consider it important that at some future date the Canadian and selected world-wide records of this earthquake be examined with a view to deriving the depth and focal mechanism by modelling the seismograms.

FOCAL MECHANISM

The ISS gives 24 reported polarities (eight in California), all but SFA, MNT and CRT being compressions. BCIS gives four additional polarities (two dilatations and two compressions, including the only polarity from the western quadrant, from MAT), and we added the VIC and HAL readings (Table 5). Polarities from western North America and central Asia are consistently compressions, while European and eastern North American polarities are dominantly compressions. We examined the MNT and SFA records and consider the SFA polarity reading dubious at best. The MNT first motion direction is clear, but the photographic annotation of the sheet is reversed relative to the normal (i.e. the words are laterally-reversed by placing the photographic paper upside down in the template printer), and so ambiguous as to the "up" direction. At least one of the local blasts has a first motion in the same direction as the earthquake, raising questions about the reported polarity. The MNT reading is very close to the OTT reading which is a C, and for the reasons above we choose to ignore the MNT reading.

In addition to the P-wave polarities we also read an excellent S polarity (DSW) on RES.

Fig. 6 shows plots of data (top left) and representative planes that fit the P-wave polarities (top right), as computed for a 15^0 grid search of the focal sphere. The available P data are insufficient to determine the likely mechanism, but it is clear from the corresponding distribution of P, T, and B axes (obscured) that allowable mechanisms would be those with thrust/strike-slip or strike-slip faulting, and that normal faulting mechanisms are very unlikely. A mechanism with dip, strike, and rake parameters 73, 297, –14 (found by a 1^0 grid search) can fit the CRT and KSA dilatation polarities at the expense of misfitting the MAT compression. Additional polarities from COL, eastern Siberia, Japan, or China might confirm the MAT reading, and so eliminate these nearly pure strike-slip mechanisms.

The RES S-wave polarity indicates motion back towards the earthquake and to the right (when the observer faces the station with back to the event), and is shown in Table 5 in the FOCMEC convention. Using these data as additional constraints dramatically reduces the possible solutions (Fig. 6, centre; the S-wave nodal surfaces are given at the bottom of the figure). Two families of solutions are possible:

- a set with steeply-dipping B-axes that represent strike-slip faulting (with a small normal component). All misfit the compression at MAT, but a subset with more northerly trending B-axes fits the dilatations at CRT and KSA.
- a set with moderately-dipping, northwest-trending B-axes that represent strike-slip/thrust faulting. Because all fit MAT (but misfit CRT and KSA), this solution with dip, strike, and rake parameters 62, 272, 28 ($\pm 5^0$ on each parameter) is weakly preferred.

The allowable nodal planes are too disparate to discuss their seismotectonic implications, but the P-axes are confined to the ENE octant. Methods more sophisticated than P-nodal and S-nodal solutions (including the modelling of selected seismograms) will be needed for a more definitive answer. It should be noted that previous stress data, mostly from oilwell breakouts and a few strike-slip earthquake mechanisms suggest northeast-directed compression (Adams, 1987; Adams and Bell, 1991), i.e., parallel to the Arctic margin, and consistent with either of the families of solutions.

SEISMOTECTONIC SETTING

The Arctic Margin earthquake of 1956 lies near the southwest margin of a diffuse cluster of earthquakes northwest of Ellef Ringnes Island and north of Borden Island (Fig. 7). The cluster is approximately 300 km E-W by

200 km N-S. All but two of the earthquakes known in this cluster postdate 1961 (Basham et al., 1977), and so are expected to be relatively well located, especially as the same seismograph stations (MBC, RES and ALE) have been in continuous operation. Therefore, the recent project to recompute all instrumental earthquakes to modern levels did not result in the cluster being better defined, as happened, for example, for the Lower St. Lawrence (Adams et al., 1989) and Laurentian Slope (Adams, 1986) seismic zones. A systematic study of these earthquakes is still justified.

Six of the earthquakes in the cluster (all occurred between 1972 and 1975 and had magnitudes of 4.1 to 5.0) were used by Basham et al. (1982) for the definition of the Gustaf-Lougheed Arch seismic zone, but the cluster as a whole was not treated as a seismic zone.

Adams and Basham (1989, but written 1987-88) noted that the seismicity along the Arctic Ocean margin was concentrated in distinct clusters in the Beaufort Sea and northwest of Ellef Ringnes Island, with only very scattered activity elsewhere (Basham et al., 1977; Wetmiller and Forsyth, 1978; Hasegawa et al., 1979; Forsyth et al., 1990). The rifted margin was formed in early Cretaceous time, possibly when northern Alaska rotated anticlockwise away from Arctic Canada (Sweeney et al., 1978). The ocean-continent transition is characterized by a zone of negative magnetic anomalies that extend from the Beaufort Sea to north of Ellesmere Island. A series of free-air gravity anomalies, elliptical in shape lie over major sediment accumulations near the shelf-slope break.

Forsyth et al. (1990) have recently provided the following interpretation of the seismicity in terms of gravity and magnetic anomalies, bathymetry, and margin structures: The zone of rift faults separating continental and oceanic crust is inferred to lie immediately seaward of the magnetic lows. Although four major elliptical gravity anomalies lie along the margin, significant seismicity is associated with them only where the shelf break extends distinctly seaward of the magnetic low; i.e. where the sediments have prograded over more oceanic crust. This suggests that earthquakes occur on the rift-related structures chiefly where the oceanic or transitional crust is loaded by sediments. Seismicity is much lower where the sediment is loading continental crust (e.g. northwest of Banks Island). Perhaps for similar reasons, very little of the Beaufort seismicity extends landward of the gravity and magnetic anomalies, though the seismicity northwest of Ellef Ringnes Island (which includes the 1956 earthquake and the cluster discussed above) extends onto the shelf and may connect with the seismicity of the Gustaf-Lougheed Arch discussed above.

Atkinson et al. (1988) placed earthquakes in the cluster into a "Canada Basin" seismic zone, but also followed Adams and Basham (1989) by suggesting two alternative source zones that **A)** treated the Arctic margin as a single source zone (with the sporadic activity being due to the short period of observation) and **B)** included the Gustaf-Lougheed Arch zone of Basham et al. (1982), with the computed seismic hazard being taken as the largest resulting from any of the models.

Our revised epicentre for the 1956 earthquake places it 50 km closer to the centre of the cluster than when it was placed at the USCGS epicentre, but still on the edge of the elliptical free-air anomaly of Forsyth et al. (1990, figure 4). We expect that with the systematic relocation of all the other nearby earthquakes the cluster will justify its own earthquake source zone in the next seismic hazard model for Canada.

CONCLUSIONS

This preliminary study of the 1956 Arctic Margin earthquake has revised its epicentre slightly and increased its magnitude significantly from 5.0 to 5.7. It also suggests that a detailed study of the entire cluster of earthquakes off Borden Island is still required.

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FIGURE CAPTIONS

Figure 1. Map of the Arctic margin showing clusters of seismicity in the Beaufort Sea (at left) off Borden Island (centre) and the single magnitude 5 earthquake off Cape Prince Alfred (north of the Beaufort Sea cluster). Earthquakes are shown complete to 1992 according to the current CEEF.

Figure 2. Map of the Arctic margin showing only the larger earthquakes (M>5). Legend as Fig. 1.

Figure 3. Detailed map showing past epicentres proposed for the Arctic Margin earthquake of 1956 (see Table 1), and our preferred epicentre (star). Crosses labelled 1, 2, .. show epicentres determined by – 1: USCGS and CEEF, 2: BCIS, 3: ISS, 4: Sykes, 1965, 5. R. G. North, 1990, 6: this report, 'close' stations, 7: this report, 4 P and 2 S phases (preferred epicentre), 8: this report, 4 P and 1 S phases, 9: this report, 4 P phases only. Dashed circle has a radius of 20 km about the preferred solution.

Figure 4. Copy of epicentre card with Canadian phases and Smith's handwritten annotations regarding the magnitude.

Figure 5. Figure (top) showing the number of seismograph stations in the world and the maximum number reporting for a single earthquake during the twentieth century and (bottom) the suggested relationship between earthquake magnitude and fraction of the stations recording the earthquake (both taken from EPRI, 1989). Arrows for the 1956 earthquake have been added.

Figure 6. Top: first motion polarities (left), allowable nodal planes and corresponding P, T, and B axes (right) from P-wave polarity data. Centre: allowable P-nodal planes that also fit the S-wave polarity data from RES. Bottom: nodal surfaces for SV and SH radiation corresponding to the allowable P-nodal planes.

Figure 7. Detail of Fig. 1 showing the earthquakes cluster off Borden Island. Epicentres shown are preliminary revisions determined by Adams, Drysdale and Wetmiller (JD database and JEEF catalog) during a wholesale recomputation of eastern Canadian epicentres. The preferred epicentre for the Arctic Margin earthquake of 1956 is the solid star at 79.83°N 116.99°W.

TABLE CAPTIONS

Table 1. Epicentral solutions for the 1956 Arctic Margin earthquake

Table 2. Data for computing M_S Marshall-Basham.

Table 3. Data for computing M_S Prague.

Table 4. Data for computing m_b.

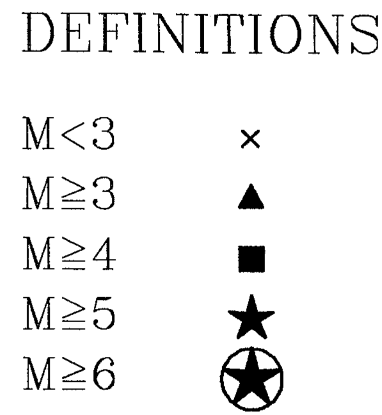
Table 5. Polarities available for the 1956 Arctic Margin earthquake.

APPENDICES

Appendix A. ISS data for the 1956 Arctic Margin earthquake.

Appendix B. 'PIK' file for proposed epicentre. See Appendix C for a description of the format.

Appendix C. PIK file format.



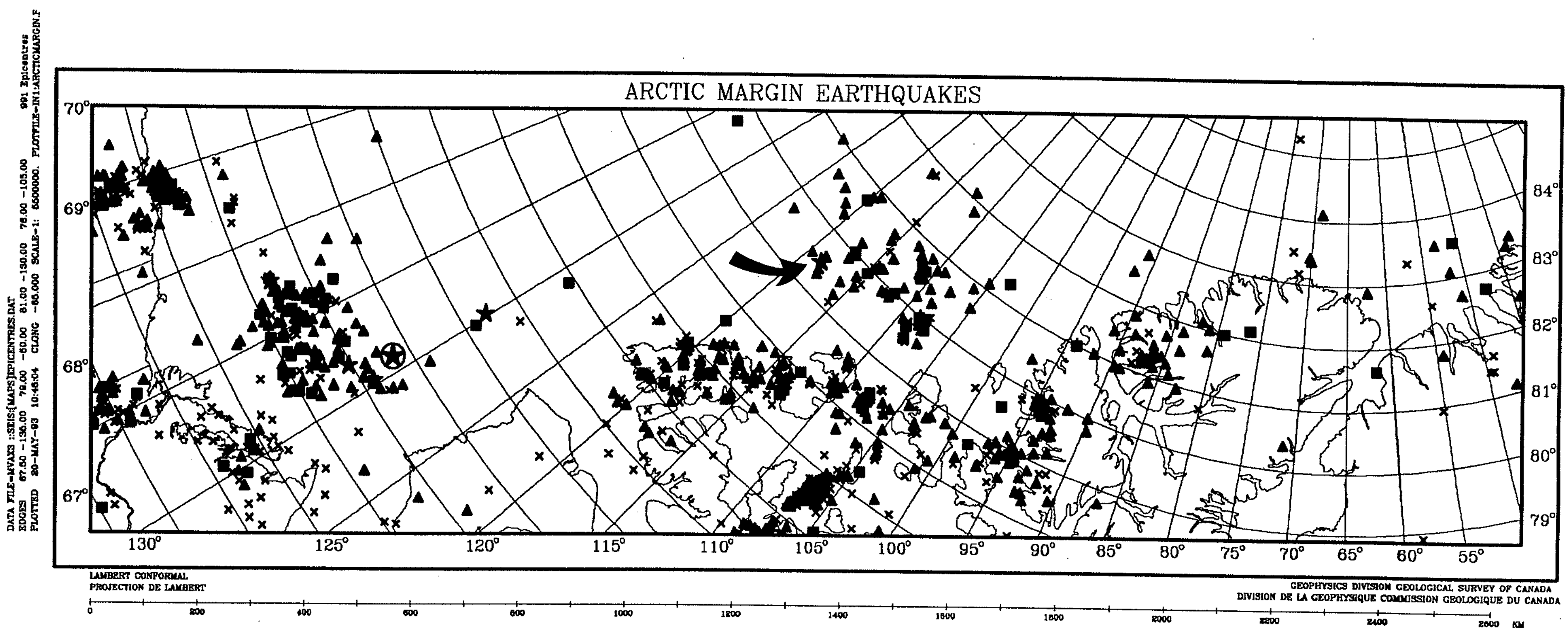
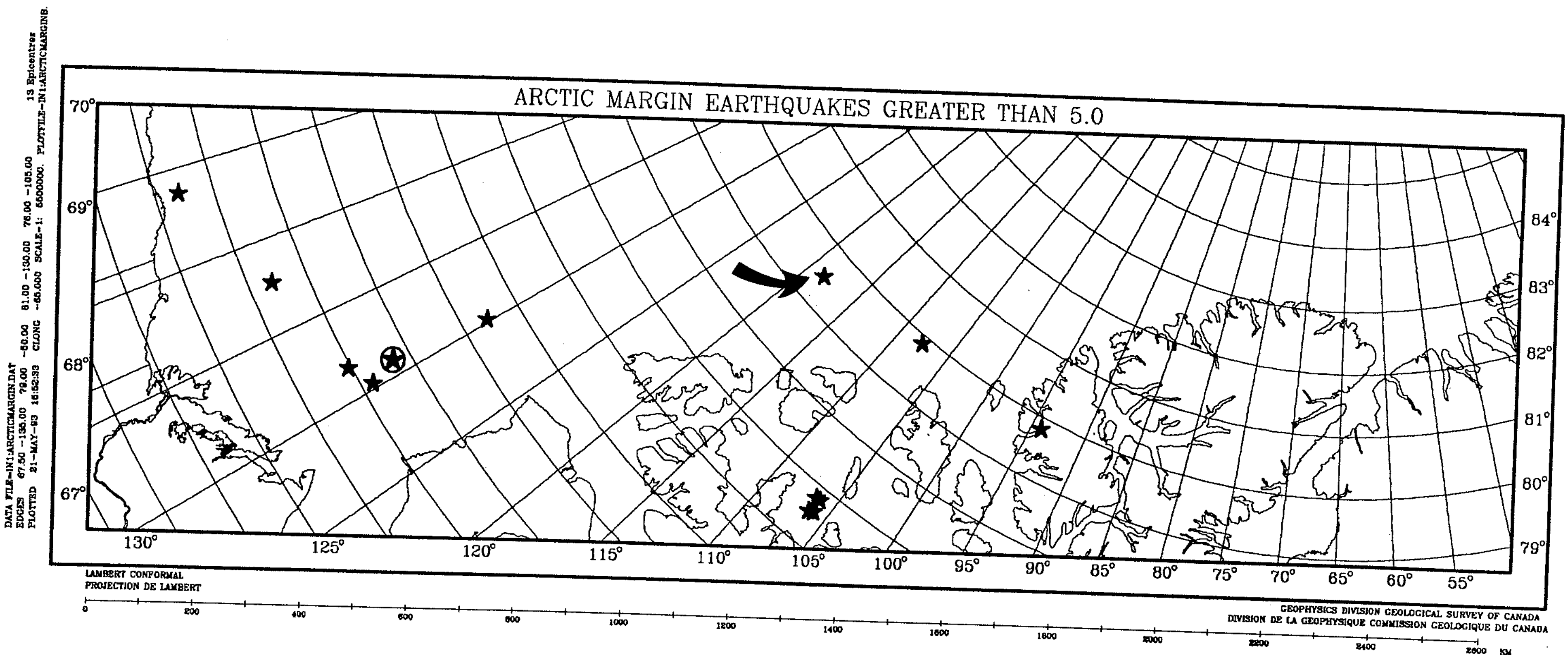


Figure 1. Map of the Arctic margin showing clusters of seismicity in the Beaufort Sea (at left) off Borden Island (centre) and the single magnitude 5 earthquake off Cape Prince Alfred (north of the Beaufort Sea cluster). Earthquakes are shown complete to 1992 according to the current CEEF.

Figure 2. Map of the Arctic margin showing only the larger earthquakes (M>5). Legend as Fig. 1.



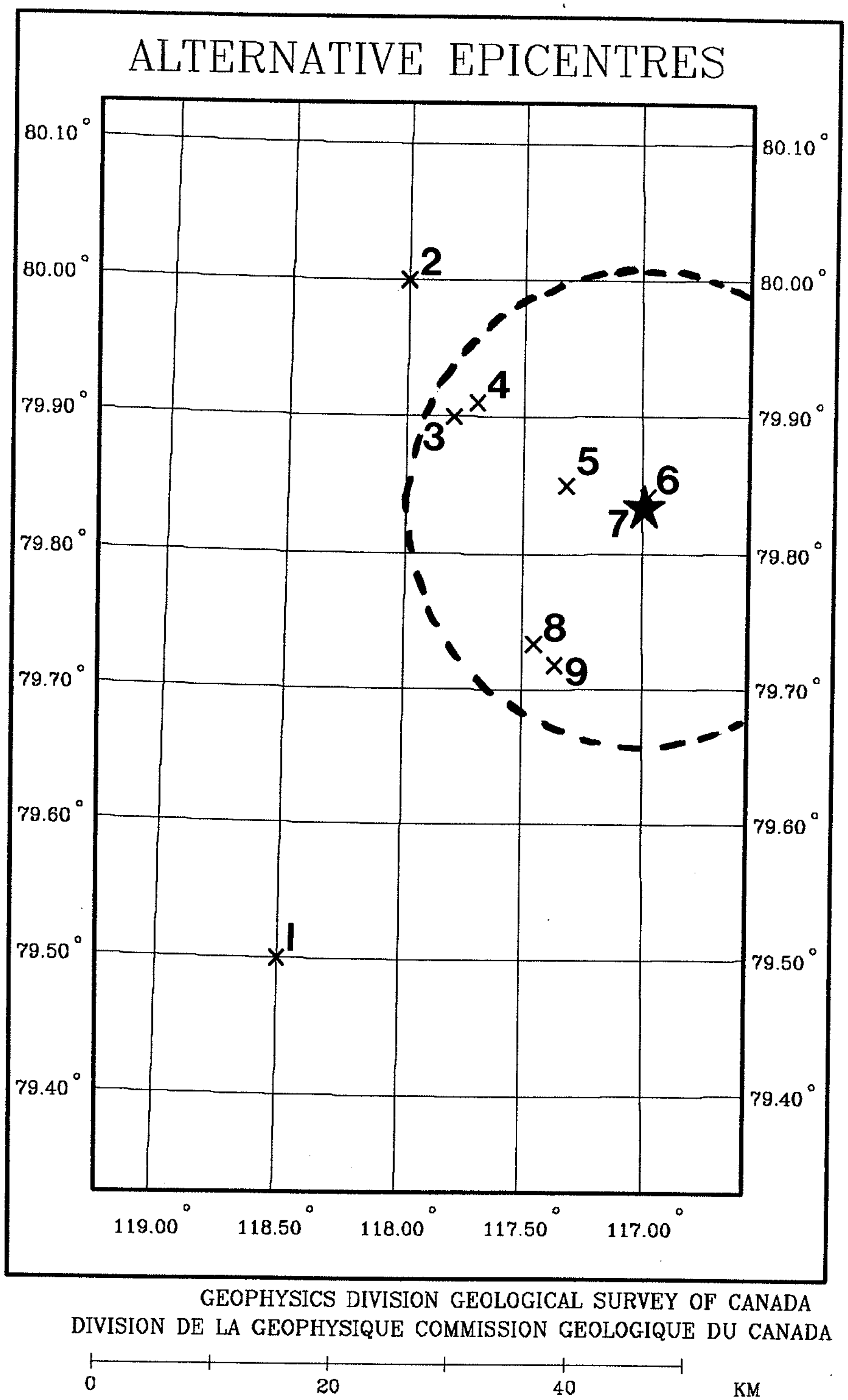


Figure 3. Detailed map showing past epicentres proposed for the Arctic Margin earthquake of 1956 (see Table 1), and our preferred epicentre (star). Crosses labelled 1, 2, .. show epicentres determined by – 1: USCGS and CEEF, 2: BCIS, 3: ISS, 4: Sykes, 1965, 5. R. G. North, 1990, 6: this report, 'close' stations, 7: this report, 4 P and 2 S phases (preferred epicentre), 8: this report, 4 P and 1 S phases, 9: this report, 4 P phases only. Dashed circle has a radius of 20 km about the preferred solution.

Earthquakes of the Canadian Arctic

JUNE 3	
U.S.C.G.S.	
79 1/2N, 118 1/2W	
Arctic Ocean	
H = 05 19 23	
Halifax	
e(L)	05 36
e	05 39 54
Kirkland Lake	
eP	05 26 12 c
e	05 38 05
e	05 40.5
i	05 41 04
Ottawa	
iP	05 26 41 c
i	05 26 52
PP	05 28 02
PPP	05 28 32
S	05 32 32
SS	05 34 51
eL	05 36.3

Resolute *Δ = 800km*	
iP	05 21 07 c
eS	05 22 23
me 23 mm @ 12.0 sec on LPEW Spreng.	
Saskatoon	
eS	05 34.1
Seven Falls	
iP	05 26 33 d
eS	05 32 17
SSS	05 35 52
eL	05 38 01
Shawinigan Falls	
eP	05 26 34 c
PP	05 27 55
PPP	05 28 19
Victoria	
iP	05 25 48
eS	05 36 12
e	05 39.3

June 3, 1956
H = 05 19 23
Mag. 5.0(?)

The magnitude is doubtful because the curves of these instruments differ so greatly from the general shape of a standard W.A. calibration curve. The shock is probably at least M = 6.

Figure 4. Copy of epicentre card with Canadian phases and Smith's hand-written annotations regarding the magnitude.

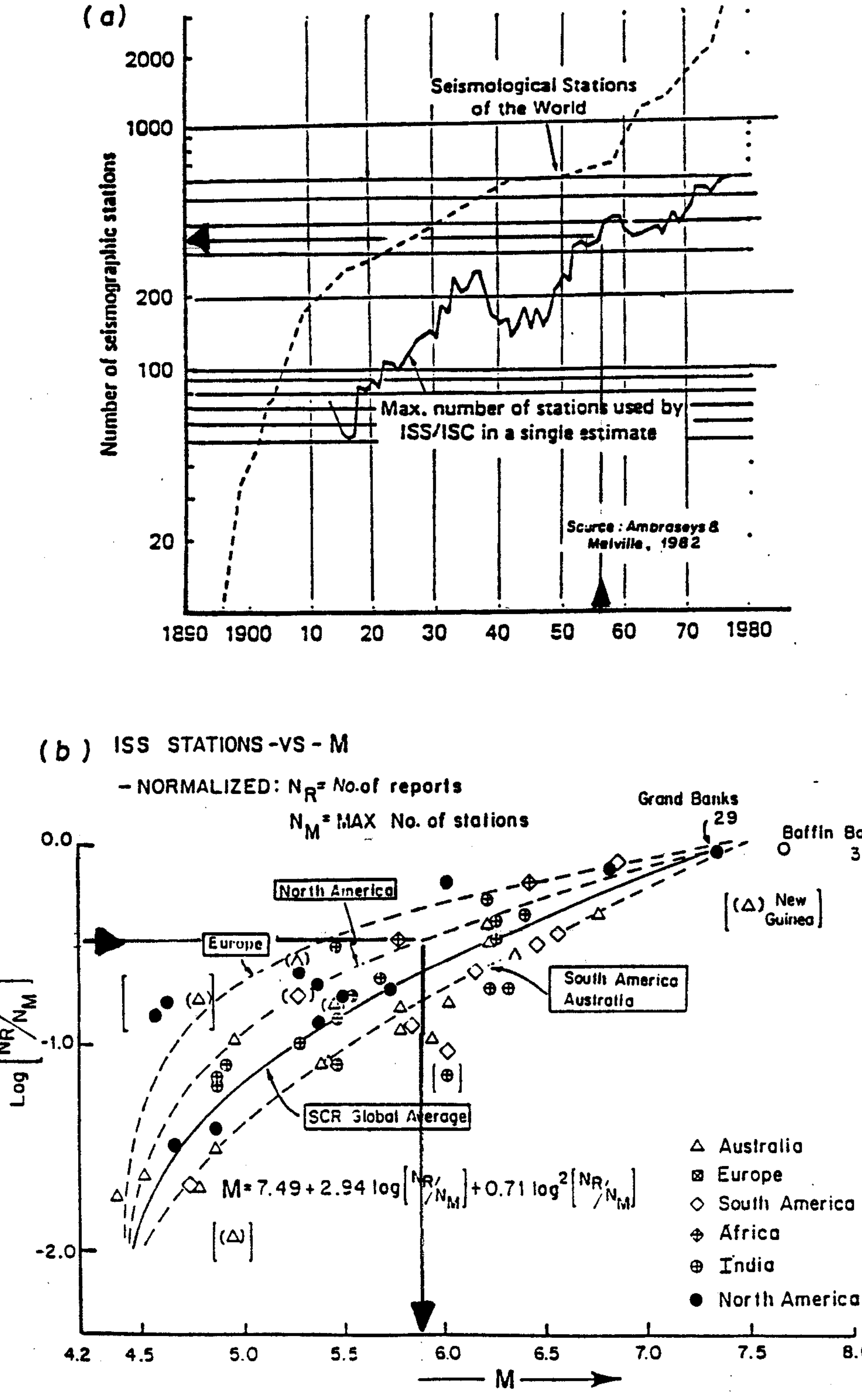


Figure 5. Figure (top) showing the number of seismograph stations in the world and the maximum number reporting for a single earthquake during the twentieth century and (bottom) the suggested relationship between earthquake magnitude and fraction of the stations recording the earthquake (both taken from EPRI, 1989). Arrows for the 1956 earthquake have been added.

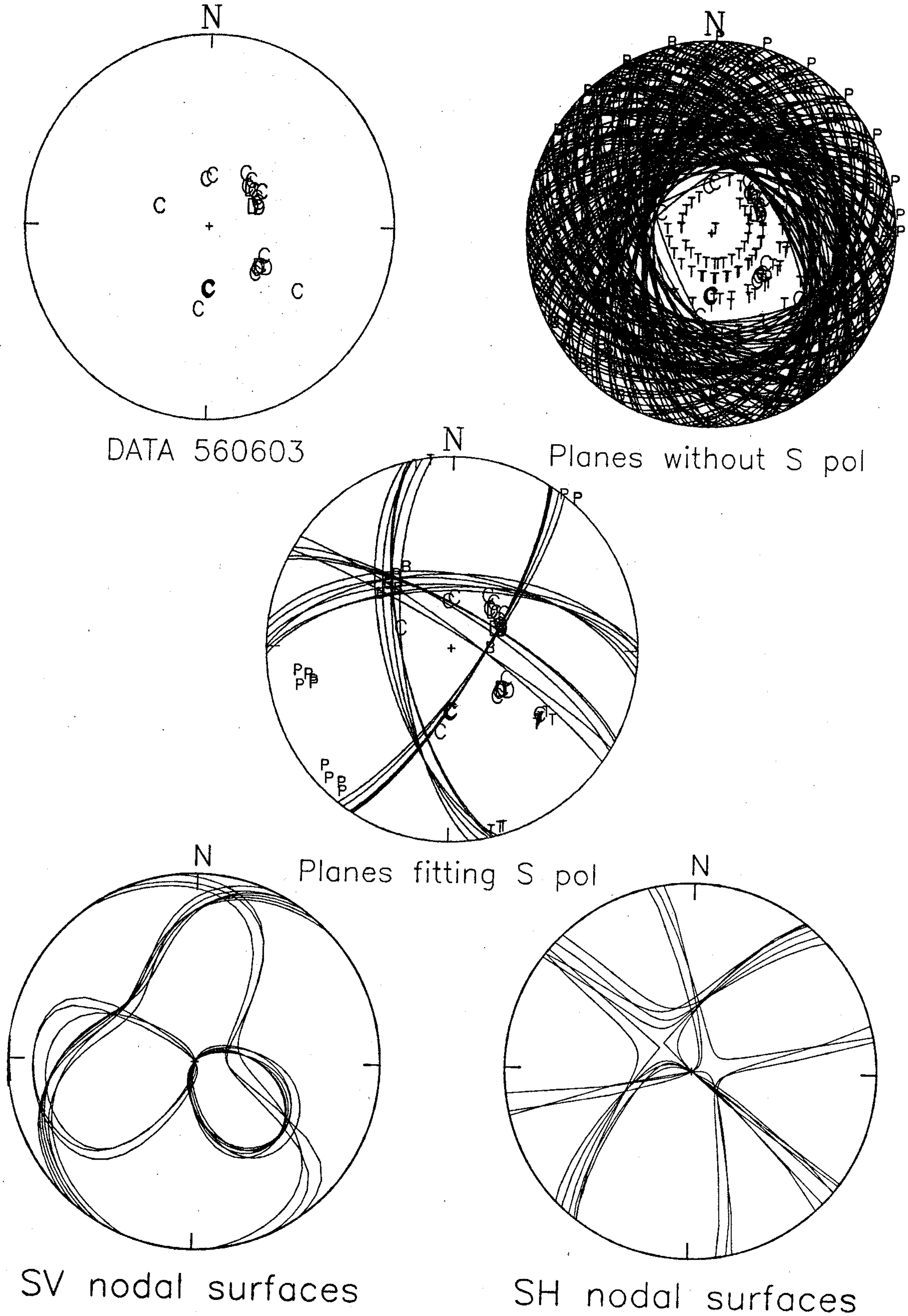


Figure 6. Top: first motion polarities (left), allowable nodal planes and corresponding P, T, and B axes (right) from P-wave polarity data. Centre: allowable P-nodal planes that also fit the S-wave polarity data from RES. Bottom: nodal surfaces for SV and SH radiation corresponding to the allowable P-nodal planes.

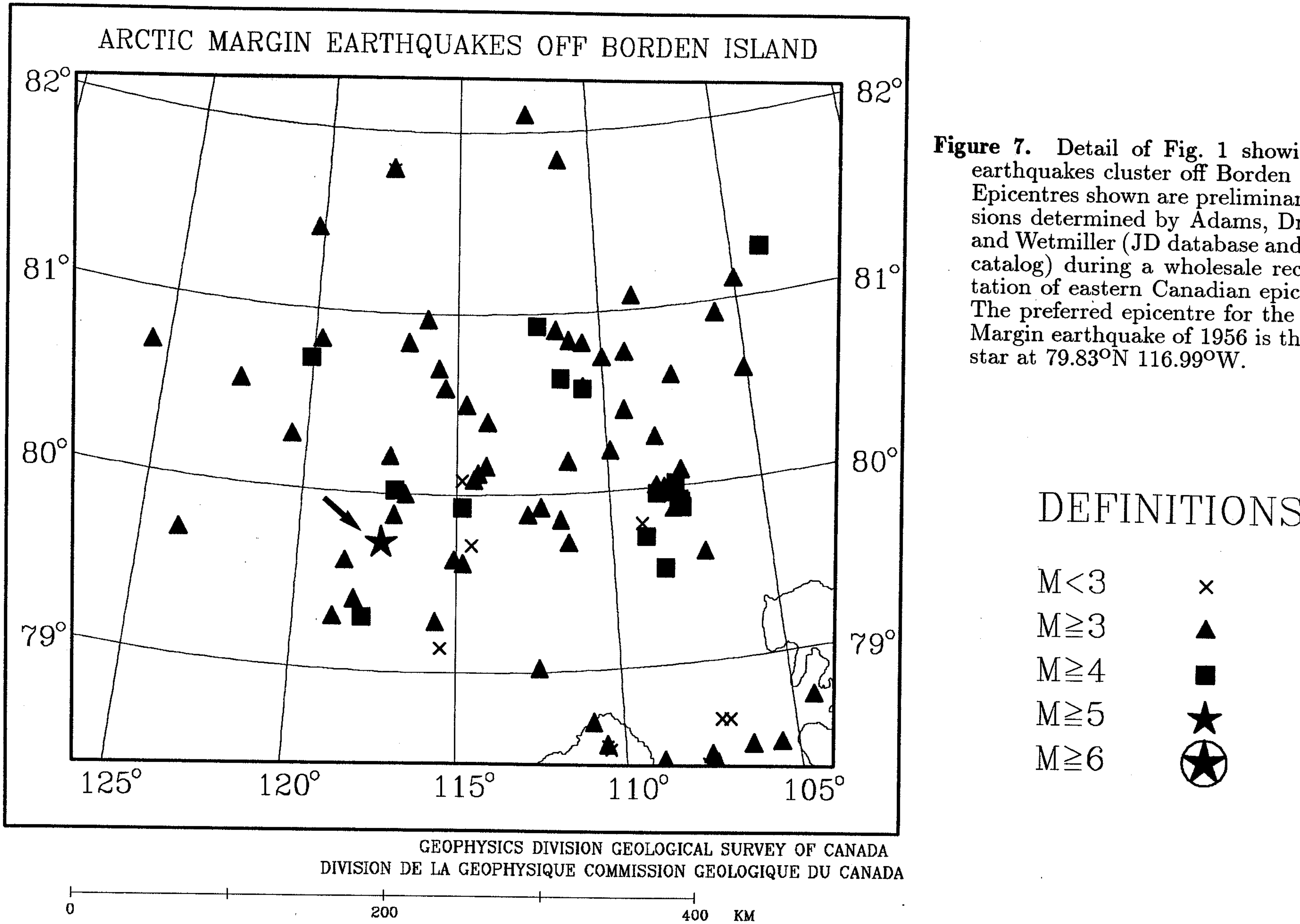


Figure 7. Detail of Fig. 1 showing the earthquakes cluster off Borden Island. Epicentres shown are preliminary revisions determined by Adams, Drysdale and Wetmiller (JD database and JEEF catalog) during a wholesale recomputation of eastern Canadian epicentres. The preferred epicentre for the Arctic Margin earthquake of 1956 is the solid star at 79.83°N 116.99°W.

TABLE 1

EPICENTRAL SOLUTIONS FOR THE 1956 ARCTIC MARGIN EARTHQUAKE

Date	HH	MM	SS.S	LAT		LONG		Fig 3	SOURCE
1956060305	19	23		79.5	N	118.5	W	1	USCGS and CEEF89
	19	22		80.0	N	118.0	W	2	BCIS
	19	23		79.9	N	117.8	W	3	ISS
	19	23.2		79.91	N	117.70	W	4	Sykes (1965)
	19	27.8		79.85	N	117.32	W	5	North (pers. comm., 1990)
	19	26.8		79.84	N	116.97	W	6	This report - 'close' stations
	19	26.6		79.83	N	116.99	W	7	This report - 4P,2S (preferred)
	19	26.3		79.73	N	117.45	W	8	This report - 4P,1S
	19	26.2		79.72	N	117.36	W	9	This report - 4P

TABLE 2

Data for computing Marshall-Basham Ms from the equation: Ms = log(Ag) + B′(delta) + P(T)

Station	Distance km	Distance Deg	Component	At (mm)	T (s)	K	Ag (nm)	B′(delta)	P(T)	Ms	
RES	778	7.0	Press LPZ	>41.5	16.0	785	>52900	0.90	-0.30	>5.32	*
VIC	3497	31.5	Benioff LPZ	6.25	16.0	510	12260	1.45	-0.30	5.23	*
OTT	4175	37.6	Benioff LPZ	13.0	11.6	5280	2462	1.55	-0.64	4.30	
HAL	4457	40.2	Benioff LPZ	1.5	14.0	179	8380	1.57	-0.46	5.03	
									Adopted Value	5.4	

Notes: P(T) is taken from Table 2 of Marshall and Basham (1972) for the ′continental N. America′ path
RES magnitude was increased by 0.3 units because the maximum amplitude was not readable; see text
OTT Benioff LPZ magnification uncertain; see text
HAL Benioff LPZ magnification uncertain; see text
* values used in calculating the adopted magnitude

TABLE 3

Data for computing Ms (Prague) from the equation: Ms (Prague) = log(Ag/T) + 1.66*log(delta) + 0.3

Station	Distance km	Distance Deg	Component	At (mm)	T (s)	K	Ag (nm)	A/T RMS (nm/s)	Ms	
RES	778	7.0	Sprengnether LPNS	21.5	6.0	1832	11700	2310	5.06	
			Sprengnether LPEW	22.5	14.5	1257	17900			
SAS	3110	28.0	Milne-Shaw NW	2.25	5.6	140	12500	2830	6.15	
			Milne-Shaw NE	1.75	7.5	134	13060			
VIC	3497	31.5	Benioff LPNS	6.0	5.5	1142	5250	1120	5.84	*
			Benioff LPEW	3.75	5.5	1428	2630			
SFA	4064	36.6	Milne-Shaw EW	1.8	9.0	258	6980	>775	>5.78	*
OTT	4175	37.6	Milne-Shaw EW	1.75	10.0	251	6970	916	5.87	*
			Milne-Shaw NS	1.5	12.0	210	7140			
HAL	4457	40.2	Sprengnether LPEW	3.0	9.0	1047	2870	375	5.54	*
			Sprengnether LPNS	3.0	14.0	1077	2790			
								Adopted Value	5.8	

Notes: RES magnitude at too close a distance
SAS seismometers not on bedrock; site amplification a possibility
SFA magnitude is a minimum because only 1 horizontal component was recorded
* values used in calculating the adopted magnitude

TABLE 4

Data for computing Mb from the equation: Mb = log(Ag/T) + q * (delta)

Station	Distance km	Distance Deg	Component	At (mm)	T (s)	K	Ag (nm)	q (delta) (nm/s)	Mb	
VIC	3497	31.5	Benioff SPZ	1.6	0.6	36700	43	3.7	5.56	*
SFA	4064	36.6	Benioff SPZ	1.2	0.8	?50000	24	3.5	4.98	
OTT	4175	37.6	Benioff SPZ	4.6	1.2	28800	160	3.5	5.62	*
			Benioff LPZ	4.4	1.3	34800	126	3.5	5.49	
MNT	4195	37.8	Benioff SPZ	3.0	1.3	?	?	?	?	
HAL	4457	40.2	Benioff LPZ	0.7	1.1	2200	320	3.4	5.86	*
								Adopted Value	5.7	*

Notes: SFA magnification uncertain, see text
OTT Benioff LPZ magnification uncertain; see text
* values used in calculating the adopted magnitude

TABLE 5

POLARITIES AVAILABLE FOR THE 1956
ARCTIC MARGIN EARTHQUAKE

ID	AZIMUTH	TAKE-OFF	POL	SOURCE
RES	124.4	49.0	C	ISC AND ADAMS
RES	124.4	49.0	B	ADAMS S-wave goes D on vertical
RES	124.4	49.0	>	ADAMS S-wave goes SW on = 'right'
VIC	187.0	35.5	C	ADAMS
KLC	133.6	28.5	C	ISC AND ADAMS
SFA	124.0	31.0	-	ISC=D; ADAMS=?
SHF	125.8	28.4	C	ISC AND ADAMS
OTT	129.5	27.8	C	ISC AND ADAMS
MNT	127.0	27.8	e	ISC=D; ADAMS=?
UPP	35.0	27.8	C	ISC AND BCIS
HAL	116.4	27.5	C	ADAMS
DUB	57.0	27.5	C	ISC AND BCIS
TIN	180.5	27.0	C	ISC
HAM	43.0	27.0	C	ICS
CLC	179.8	26.8	C	ISC
ISA	180.8	26.8	C	ISC
WDY	181.2	26.8	C	ISC
PAS	180.5	26.4	C	ISC
RVR	179.5	26.4	C	ISC
PLM	178.9	26.2	C	ISC
BAR	178.7	25.9	C	ISC
CFF	51.4	25.0	C	ISC AND BCIS
FIR	44.0	24.0	C	BCIS
MON	48.0	24.0	D	BCIS
TOL	59.3	24.3	C	ISC AND BCIS
LIS	64.0	23.9	C	ISC
MAT	291.0	23.8	C	BCIS
CRT	69.0	23.4	D	ISC AND BCIS
ASH	3.0	21.8	C	ISC
KSA	65.5	21.0	D	BCIS
QUE	355.6	20.2	C	ISC

APPENDIX A.

ISS data for the 1956 Arctic Margin earthquake.

June 3d. 5h. 19m. 23s. Epicentre 79°·9N. 117°·8W.

A = −·0824, B = −·1562, C = +·9843 ; δ = +3 ; h = −14 ;
D = −·885, E = +·466 ; G = −·459, H = −·871, K = −·176.

		Δ °	Az. °	P. m. s.	O − C. s.	S. m. s.	O − C. s.	Supp. m. s.		L. m.
Resolute		7·2	125	i 1 44a	− 5	e 3 0	−13	—	—	—
College		17·2	226	i 4 0	− 3	i 7 2	−12	e 4 26	PPP	e 7·9
Scoresby Sund		22·9	59	e 5 6	0	i 9 23	+10	e 5 34	PP	12·2
Sitka		23·6	204	e 5 13	0	e 9 31	+ 6	e 5 37	PP	e 10·8
Tiksi		24·3	315	e 5 20	0	e 9 40	+ 3	e 6 2	PP	—
Kiruna		30·6	30	i 6 16	− 2	e 11 19	− 1	i 9 20	PcP	—
Victoria		31·6	187	i 6 25	− 1	e 16 49	L	—	—	(e 16·8)
Hungry Horse		31·7	175	i 6 26	− 1	e 12 20	SS	i 7 21	PP	i 13·3
Magadan		32·3	288	e 6 39?	+ 6	—	—	—	—	—
Seattle		32·4	186	e 6 44	+10	e 8 29	?	e 7 16	PP	e 13·6
Skalstugan		33·9	38	i 6 46	− 1	—	—	—	—	—
Butte	N.	34·1	174	i 6 48	0	e 11 46	−28	i 7 56	PP	e 14·0
Bozeman		34·5	172	i 6 51	− 1	e 12 4	−16	e 8 3	PP	e 14·4
Kirkland Lake	Z.	34·5	134	e 6 49a	− 3	—	—	—	—	e 18·7
Corvallis	E.	35·5	187	e 7 1	+ 1	—	—	—	—	—
Rapid City	E.	36·4	162	i 7 8	0	—	—	—	—	—
Seven Falls		36·8	124	i 7 10k	− 1	e 12 54	− 2	16 29	?	e 18·6
Shawinigan Falls		37·0	126	e 7 11a	− 2	8 32	PP	8 56	PPP	—
Petropavlovsk		37·1	277	e 7 23	+ 9	—	—	e 16 3	SS	—
Ottawa		37·8	130	i 7 18a	− 2	13 9	− 2	8 39	PP	e 16·9
Brébeuf		38·0	127	i 7 19k	− 2	—	—	—	—	—
Upsala		38·1	35	i 7 21a	− 1	e 13 6	−10	i 9 44	PcP	—
Aberdeen		38·4	52	i 16 55	?	—	—	—	—	—
Pulkovo		39·3	25	e 7 33	+ 1	—	—	—	—	—
Salt Lake City		39·4	173	i 7 33	0	e 12 37	−58	—	—	e 16·2
Shasta	Z.	39·4	186	e 7 32	− 1	—	—	—	—	—
Mineral	Z.	39·7	185	e 7 36	0	—	—	—	—	—
Boulder		40·3	165	e 7 41	+ 1	—	—	—	—	—
Reno	Z.	40·5	182	e 7 43	+ 1	—	—	—	—	—
Eureka		40·6	178	i 7 35	− 8	—	—	i 9 37	PcP	e 19·1
Rathfarnham C.	Z.	41·5	57	i 7 50a	0	—	—	—	—	—
Copenhagen		41·7	41	i 7 53	+ 1	i 14 14	+ 4	e 17 13	SS	21·6
Pennsylvania		42·0	133	i 7 55	+ 1	e 14 13	− 1	e 9 35	PP	—
Berkeley		42·2	185	e 7 57	+ 1	e 14 22	+ 5	—	—	—
Terre Haute		42·2	144	e 14 7	S	(e 14 7)	−10	—	—	i 21·6
Palisades		42·3	129	i 7 57	0	e 14 19	0	e 9 32	PP	e 21·6
Lick	Z.	42·7	184	i 8 2	+ 2	—	—	—	—	—
Morgantown		42·9	136	i 8 1	− 1	—	—	i 9 37	PP	—
Tinemaha	Z.	43·0	180	i 8 5a	+ 2	—	—	i 9 59	PP	—
Philadelphia		43·2	130	e 8 5	+ 1	e 14 32	0	—	—	e 17·9
Fresno	Z.	43·3	182	i 8 6	+ 1	—	—	—	—	—
Hamburg		43·5	43	i 8 7a	0	—	—	e 9 59	PP	e 30·6
Sverdlovsk		43·5	1	8 6	− 1	14 36	0	9 56	PP	—
Moscow		43·8	20	i 8 9	0	e 14 41	+ 1	—	—	—
Witteveen	Z.	43·8	46	e 8 10	+ 1	—	—	—	—	—
Washington	Z.	44·0	133	i 8 9	− 2	e 15 52	+69	—	—	—
Boulder City		44·1	177	i 8 11	− 1	—	—	e 9 58	PP	—
China Lake	Z.	44·2	180	i 8 14a	+ 2	—	—	i 10 6	PP	—
Kew		44·2	53	e 8 19	+ 7	e 14 45	− 1	—	—	e 25·6
De Bilt		44·3	48	e 8 11	− 2	e 14 49	+ 1	—	—	e 26·6
Isabella	Z.	44·4	181	i 8 14a	0	—	—	i 10 6	PP	—
Woody	Z.	44·4	181	i 8 13a	− 1	e 12 31	?	i 10 2	PP	—
Fayetteville		44·9	153	i 8 16	− 2	e 15 5	+ 9	—	—	—
Uccle		45·5	49	e 8 22	− 1	e 14 59	− 6	—	—	—
Yuzno-Sakhlinsk		45·8	290	i 8 25	0	e 15 9	0	—	—	—
Irkutsk		45·9	325	8 24	− 2	e 15 8	− 3	e 10 22	PP	—
Pasadena		45·9	180	i 8 26a	0	i 18 32	ScS	i 10 19	PP	i 22·3
Riverside	Z.	46·0	180	i 8 27a	0	—	—	i 10 12	PP	—
Warsaw		46·0	34	e 10 17	PP	e 13 50	PcS	e 14 38	PS	e 21·6
Jena		46·2	43	e 8 28	0	e 10 10	PP	e 10 46	PPP	—

Continued on next page.

		Δ °	Az. °	P. m. s.	O − C. s.	S. m. s.	O − C. s.	Supp. m. s.		L. m.
Chapel Hill		46·7	136	e 8 30	− 2	—	—	—	—	—
Palomar	Z.	46·7	179	i 8 33a	+ 1	—	—	i 10 6	PP	—
Paris		47·2	51	i 8 35	− 1	e 15 27	− 2	i 10 7	PcP	e 27·6
Barratt	Z.	47·4	179	i 8 38a	0	—	—	i 10 9	PP	—
Prague		47·4	40	i 8 39?	+ 1	e 10 4	PcP	e 11 0	PPP	—
Tucson		47·9	172	i 8 41	− 1	e 15 41	+ 2	—	—	e 24·4
Strasbourg		48·1	47	e 8 43	0	e 15 46	+ 4	e 10 18	PcP	e 28·1
Stuttgart		48·1	45	e 8 42	− 1	e 15 47	+ 5	e 19 37	SS	e 27·6
Columbia		48·3	138	i 8 43	− 2	e 15 41	− 4	e 10 34	PP	e 21·5
Ebingen		48·6	46	e 8 47	0	—	—	—	—	—
Lwow		48·7	32	i 8 48	0	e 15 51	+ 1	e 10 11	PcP	—
Basle		49·1	47	e 8 54	+ 3	—	—	—	—	—
Besançon		49·2	48	i 8 51	− 1	e 10 41	PP	e 10 10	PcP	—
Semipalatinsk		49·5	345	e 8 53	− 1	—	—	—	—	—
Bratislava		49·6	38	i 8 55	0	e 16 7?	+ 4	i 10 30	PP	—
Clermont-Ferrand		50·2	51	i 9 0a	0	e 16 18	+ 7	—	—	—
Vladivostok		51·3	298	i 9 6	− 2	e 16 26	0	—	—	—
Changchun		51·6	304	e 9 13	+ 3	—	—	—	—	—
Chihuahua		51·6	167	—	—	e 17 30	PPS	—	—	—
Iasi		51·6	30	9 22	+12	10 53	PP	10 33	PcP	—
Triest		51·7	42	e 9 9	− 2	16 39?	+ 7	e 17 28	PPS	33·0
Monaco		52·8	48	e 9 19	0	—	—	—	—	—
Florence		53·2	45	i 9 22	0	e 16 57	+ 5	e 11 25	PP	e 26·6
Simferopol		54·4	24	e 9 30	− 1	—	—	—	—	—
Toledo		55·0	59	i 9 6a	−29	17 25	+ 8	11 41	PP	—
Rome		55·2	44	e 9 37	0	e 17 19	− 1	e 21 15	SS	—
Lisbon	Z.	55·3	64	e 9 37a	− 1	—	—	—	—	—
Peking		56·6	312	e 9 45	− 2	e 17 37	− 1	—	—	—
Matusiro		56·7	291	9 46	− 2	e 17 39	− 1	e 21 33	SS	—
Alicante		57·0	56	9 49	− 1	17 44	+ 1	—	—	e 27·6
Frunse		57·2	349	i 9 52	+ 1	e 17 46	0	i 12 58	PP	i 30·7
Granada		57·7	60	i 9 56k	+ 1	17 56	+ 3	10 3	pP	28·9
Almeria		58·2	59	e 9 57	− 1	—	—	—	—	e 31·8
Tiflis		58·2	15	i 9 58	0	—	—	—	—	—
Algiers Univ.	Z.	59·0	54	e 9 58	− 6	—	—	—	—	24·6
Tashkent		59·0	354	e 10 0	− 4	e 18 1	− 9	e 13 41	PPP	—
Messina	E.	59·3	42	e 10 45	+39	e 18 35	+21	—	—	e 39·0
Relizane		59·7	56	e 10 8	− 1	—	—	—	—	—
Goris		60·5	14	i 10 14	0	i 18 33	+ 4	—	—	—
Tacubaya		61·2	160	e 10 26	+ 7	e 18 31	− 7	e 12 29	PP	—
Vera Cruz		61·6	157	—	—	e 22 3	SS	—	—	—
Stalinabad		61·7	354	i 10 22	0	—	—	—	—	—
Ashkabad		62·4	3	i 10 29a	+ 2	—	—	—	—	—
Nanking		64·0	308	e 10 36	− 2	—	—	—	—	—
Zô-Sè		64·6	306	e 10 40	− 1	e 19 20	− 1	—	—	—
Ksara		65·5	24	i 10 48	+ 1	i 19 36	+ 4	e 24 0	SS	—
San Juan		65·7	125	e 10 45	− 3	—	—	—	—	—
Dehra Dun		69·6	345	—	—	e 25 9	SS	—	—	—
Quetta		70·1	356	e 11 15a	− 1	i 20 29	+ 2	—	—	—
St. Lucia		70·7	121	i 11 17	− 3	—	—	—	—	—
St. Vincent		71·5	121	i 11 24	0	—	—	—	—	—
Barbados		71·8	119	e 11 29	+ 3	—	—	—	—	—
Tamanrasset	Z.	73·2	54	i 11 34	− 1	—	—	e 14 18	PP	—
Shillong	Z.	73·5	332	e 11 36	0	—	—	—	—	—
Bokaro	N.	75·6	338	—	—	e 29 32	SSS	—	—	—
Bogota		78·1	135	i 12 3	+ 1	i 22 36	PS	i 27 19	SS	—
Bombay		81·2	350	—	—	e 22 33	+ 4	e 28 33	SSP	—
Poona	Z.	81·5	349	i 12 20	− 1	—	—	i 29 21	SSP	—
Hyderabad	E.	82·4	344	—	—	e 30 39	SSS	—	—	—
Madras	E.	86·7	342	—	—	e 31 58	SSS	—	—	—
Huancayo	Z.	94·4	138	e 13 22	− 1	—	—	e 17 4	PP	—
Pretoria	Z.	123·8	37	e 18 30	[−30]	—	—	—	—	—
Kimberley	Z.	126·4	42	i 19 5	[0]	—	—	—	—	—

APPENDIX B

'PIK' file for proposed epicentre.
See Appendix C for a description of the format.

```
+79.834-116.991F1MB=5.7 0519266 03061956 00.0730.277 0.0  4  6  01.10 218.00    0 1ML=0.0   00   0L3.62
$79.5   118.5           051923            USCGS
$79.5   118.5     ML=5.0 051923           CEEF1988
$79.9   117.8                             I.S.S.
ARCTIC OCEAN, OFFSHORE OF BORDEN ISLAND
$
$ SOLUTION USING ONLY THE P PHASES FROM RES, COL, SCO, TIK
$+79.718-117.365F1MB=5.7  0519262 03061956 00.0520.224 0.0  4  4  00.36 218.00   0 1ML=0.0   00   0L3.62
$
$ SOLUTION USING THE P FROM RES, COL, SCO, TIK AND S FROM RES
$+79.734-117.452F1MB=5.7  0519263 03061956 00.0380.154 0.0  4  5  00.39 218.00   0 1ML=0.0   00   0L3.62
$
$ SOLUTION USING THE P FROM RES, COL, SCO, TIK AND S FROM RES AND COL
$+79.834-116.991F1MB=5.7  0519266 03061956 00.0730.277 0.0  4  6  01.10 218.00   0 1ML=0.0   00   0L3.62
$
$ SOLUTION USING 'CLOSER' STATIONS:-
$  P: RES,COL,SCO,SIT,TIK,VIC,KLC  S: RES,COL
$+79.842-116.974F1MB=5.7  0519268 03061956 00.0540.204 0.0  7  9  00.96 218.00   0 1ML=0.0   00   0L3.62
$
$ SOLUTION USING P PHASES BELOW AND S PHASES FROM RES AND COL
$      P: RES,COL,SCO,TIK    S: RES,COL
$    PREFERRED SOLUTION - SEE OPEN FILE
$+79.819-117.081F1MB=5.7  0519271 03061956 00.0420.171 0.0 11 14  00.94 218.00   0 1ML=0.0   00   0L3.62
$
$ SMITH: "THE MAGNITUDE IS DOUBTFUL BECAUSE THE CURVE OF THIS INSTRUMENT
$        DIFFERS SO GREATLY FROM THE GENERAL SHAPE OF A STANDARD W.A.
$        CALIBRATION CURVE. THE SHOCK IS PROBABLY AT LEAST A MAGNITUDE 6.0."
$
$ COMMENTS MADE BY ADAMS AND PENNEY (STUDENT FOR J. ADAMS 1990):
$ CANADIAN READINGS TAKEN FROM THE OTTAWA BULLETIN
$ I.S.S CONTAINS MUCH MORE DATA, THERE WERE 123 STATIONS REPORTING
$ BCIS HAS SOME ADDITIONAL DATA
$
$RES: TIMING GOOD TO +/- I SEC DESPITE DRIFT OF 19 S/DAY
$     SV POLARITY IS DSW
$     MAX=23 MM, PERIOD=12.0 SECONDS, TAKEN FROM SPRENGNETHER'S LPEW'S.
$     FROM CALIBRATION MADE DECEMBER 1957 VELOCITY SENSITIVITY WAS 2300X @ 12 S
$     I.E. MAGNIFICATION OF 1200 TIMES
$SCO: AN ADDITIONAL PHASE RECORDED AT 2846
$VIC: ADDITIONAL PHASE RECORDED AT 3918
$SFA: A TELESEISMIC S WAS READ AT 3217
$SHF: ADDITIONAL PHASES WERE RECORDED AT 2755 AND 2819
$OTT: AN ADDITIONAL PHASE WAS RECORDED AT 2652, 2832, 2802 AND 3618
$     A TELESEISMIC S WAS READ AT 3232
$HAL: AN ADDITIONAL PHASE WAS RECORDED AT 3654
$
$THE FOLLOWING MAGNITUDES ARE DOCUMENTED IN THE REPORT BY ADAMS AND PENNEY
$ MS=5.4 USING 4 STATIONS (MARSHALL-BASHAM)
$ MB=5.7 USING 5 STATIONS
$ MS(PRAGUE)=5.9 USING 6 STATIONS
$ M (EPRI)=5.49
$ M (#ISS)=5.9
$
$ WHEN THE CANADIAN RECORDS WERE REREAD, POSSIBLE DEPTH PHASES WERE NOTICED
$ ON HAL (P+3.8, P+6.2 SECONDS), VIC (P+3.2, P+5.7 SECONDS) OTT (P+4.4, P+6.4)
$ AND A PHASE ON CRT (P+7.0 SECONDS) WAS IDENTIFIED IN THE I.S.S. AS PP BUT
$ MIGHT BE SP. THESE PHASES SUGGEST THE DEPTH FOR THIS EVENT COULD BE
$ 13 KM (+/- 3 KM). SEE REPORT.
$
$ I.S.S CONTAINS 24 REPORTED POLARITIES WITH ALL BUT SFA, MNT AND CRT
$       BEING COMPRESSIONAL.
$ BCIS HAS 4 ADDITIONAL POLARITIES
$ ADAMS READ VIC AND HAL AS C, FOUND REPORTED SFA D DUBIOUS,
$    AND MNT STATION POLARITY AMBIGUOUS
$ THE MOST LIKELY MECHANISM IS THRUST OR THRUST/STRIKE-SLIP FAULTING.
$
$ CONTINUED ON NEXT PAGE
```

```
$
RES   5606030519P    2107   C
RES    SE 0783KM 06 -084 125 49
COL   5606030519P    2323
COL    SW 1915KM 23 -167 228 50
SCO   5606030519P    2429
SCO    NE 2540KM 14  129 060 37
SIT   5606030519P  X2436
SIT    SW 2624KM 00  080 205 36
TIK   5606030519P    2443
TIK    NW 2719KM 01 -037 316 36
SAS   5606030519P
SAS    S   3118KM        166 33
VIC   5606030519P  X2548
VIC    S   3505KM 00  091 188 32
KLC   5606030519P  X2612   C
KLC    SE 3817KM 00  038 134 32
SFA   5606030519P  X2633
SFA    SE 4069KM 00  192 124 31
SHF   5606030519P  X2634   C
SHF    SE 4100KM 00  056 127 31
OTT   5606030519P  X2641   C
OTT    SE 4180KM 00  142 130 31
MNT   5606030519P  X2642
MNT    SE 4200KM 00  088 128 31
HAL   5606030519P          C
HAL    SE 4461KM         117 30
             Z
```

```
  2223
00  021                  0000000 OOMLOOMN
  2625
16  137                  0000000 OOMLOOMN

                         0000000 OOMLOOMN
X2854
00 -052                  0000000 OOMLOOMN
X2903
00 -999$                 0000000 OOMLOOMN
            X3406
            00 1809$     0000000 OOMLOOMN
            X3612
            00 3714$     0000000 OOMLOOMN
            X3805
            00 6400$     0000000 OOMLOOMN
X3552       X3801
00 9999$00 -955          0000000 OOMLOOMN

                         0000000 OOMLOOMN
X3451
00 2548$                 0000000 OOMLOOMN

                         0000000 OOMLOOMN
X3600
00 3469$                 0000000 OOMLOOMN
```

APPENDIX C

PIK FILE FORMAT

The PIK file is the input file to and also the output file (one version newer) from the CANSESS MULTILAYER epicenter location program (LOC). SAM PIK (or PK4) command generates a PIK file automatically for the event. These PIK files can be modified/created by the EPK program or by the DEC text editor EDT.

It contains four types of records:

1. ESR - earthquake solution record.
2. ECR - earthquake comment record.
3. ODR - observed data record.
4. CDR - calculated data record.

The ESR must be the first line in the file. If the file is being located for the first time, it will be created by LOC. Otherwise it will be the output of a previous LOC.

The ECR records, containing remarks, must come before the first ODR. There is only one ODR per station, and each is followed by a CDR, which contains the calculated results for this station. The detail layout of these records is:

EARTHQUAKE SOLUTION RECORD (ESR)

(solution record has "+" or "-" in col.1 and "M" in Col. 18)

COLS	ENTRY	FORMAT	DEFINITION
1-1	+	A1	PRIME SOLUTION BY EPB
	-		PRIME SOLUTION BY OTHER AGENCY
	0		SUPPLEMENTARY 6OLUTION
2-7	45.233	F6.3	NORTH LATITIDE, DEGREES
8-15	-123.300	F8.3	LONGITUDE, DEGREES
16-16		A1	HYPOCENTRE QUALITY INDICATOR.
	O		POOR QUALITY SOLUTION
	F		GOOD QUALITY SOLUTION
17-17		I1(A1)	OBSERVED DATA FORMAT INDICATOR,
	BLANK		PRE-1979 DATA FORMAT USED
	1		1979 DATA FORMAT USED.
18-19		A2	PRIME MAGNITUDE TYPE
	ML		RICHTER
	MLE		EBEL
	MN		NUTTLI (DEFAULT)
	MLG		H. & K.
	MB		BODY-WAVE
	MS		SURFACE WAVE
	MC		CODA LENGTH
20-20	BLANK		
21-23	3.1	F3.1	AVERAGE PRIMARY MAGNITUDE VALUE
24-24	BLANK		
25-26	18	I2	ORIGIN TIME HOUR, U.T.
27-28	23	I2	ORIGIN TIME MINUTE
29-31	323	I3	ORIGIN TIME SECOND*10
32-32	BLANK		
33-34	12	I2	DAY
35-36	03	I2	MONTH
37-40	1979	I4	YEAR
41-41	BLANK		
42-42	2	I1	STANDARD DEVIATION ORIGIN TIME, SECONDS
43-47	0.122	F5.2	STD ERROR IN LATITUDE, DEGREES
48-52	0.333	F5.2	STD ERROR IN LOGITUDE, DEGREES
53-53	BLANK		
54-56	0.3	F3.1	STD ERROR IN MAGNITUDE FOR EPB
	XXX	A3	AGENCY CODE FOR EXT. MAG, DEPENDS ON COL. 1
57-59	34	I3	NUMBER OF STAIONS USED FOR HYPOCENTER
60-62	14	I3	NUMBER OF PHASES USED FOR THIS HOPOCENTER.
63-65	14	I3	NUMBER OF AMPLITUDE USED FOR MAGNITUDE.
66-69	0.33	F4.2	RMS OF HYPOCENTER SOLUTION, SECONDS.
70-70		A1	SUOLUTION TYPE INDICATOR
	BLANK		FIXED DEPTH.
	Z		FREE DEPTH
	X		NO ACTION FOR THE WHOLE FILE
	N		ASSIGNED HYPOCENTER AND TIME
	H		ASSIGNED HYPOCENTER, BUT CALCULATED ORIGIN TIME.
71-71		I1	AGENCY CODE
	1		USGS
	2		EPB
	3		PGC
	4		SEA UNIVERSITY OF WASHINGTON
	5		NEIS NATIONAL EARTHQUAKE INFORMATION CENTER
	6		ISC INTERNATIONAL SEISMOLOGICAL CENTER
	7		LDGO LAMONT-DOHERTY GEOLOGICAL OBSERVATORY
	8		WES WESTON GEOPHYSICAL OBSERVATORY
	9		UAGI UNIV. OF ALASKA, GEOPHYSICAL INSTITUTE
72-76	18.33	F5.2	FOCAL DEPTH, KM
			IF AND ONLY IF COL.70 =Z, FREE DEPTH SOLUTION
77-80	30	I4	STD ERROR IN DEPTH, IN 100rds OF METERS
81-82	03	I2	MODEL NUMBER
83-85	ML=	A3	SECONDARY MAGNITUDE TYPE
86-88	1.3	F3.1	SECONDARY MAGNITUDE VALUE
89-91	008	I3	NUMBER OF STATIONS USED TO CALCULATE SEC. MAG.
92-92	1	I1	MULTILAYER HYPO SIMULATION FLAG, 0-OFF, 1-ON.
93-93		A1	! FL001
	F		FELT ! FL001
	N," "		NOT FELT ! FL001
94-95	10	I2	NB. OF ASSOCIATED EVENTS ! FL001
96-96		A1	! FL001
	L		LOCAL EARTHQUAKE
	B		MINE BLAST
	R		ROCKBURST
	P		POSSIBLE ROCKBURST
	X		CONTROLLED EXPLOSIONS
97-100	3.56	F4.2	S VELOCITY USED BY SINGLE LAYER MODEL ! FL001

```
<     FORMAT(A1,F6.3,F8.3,2A1,A2,1X,F3.1,1X,I2.2,I2.2,I3.3,1X,2I2.2,
<     &         '19',I2.2,1X,I1,2F5.3,1X,A3,              ! FOR AGENT_CODE
<     &         '19',I2.2,1X,I1,2F5.3,1X,F3.1,            ! FOR STD_MAG>
<     &         3I3.3,F4.2,A1,I1,F5.2,I4,T81,I2,'MC=',F3.1,I3,I1,>
<     &  A1,I2,A1,F4.2)                                               >
```

EARTHQUAKE COMMENT CARDS (ECR)

COLS	ENTRY	FORMAT	DEFINITION
1-40		40A1	EARTHQUAKE DESCRIPTION IN ENGLISH
41-80		40A1	EARTHQUAKE DESCRIPTION IN FRENCH

OBSERVED DATA RECORD (ODR)

COLS	ENTRY	FORMAT	DEFINITION	
1-5	OTT	A5	STATION CODE	! FL001
6-7	79	I2	YEAR	! FL001
8-9	12	I2	MONTH	! FL001
10-11	23	I2	DAY	! FL001
12-13	12	I2	HOUR, U. T.	! FL001
14-15	14	I2	MINUTE OF 1ST P PHASE, NOT NEC. @ THIS STN	
16-16		A1	INSTRUMENT CODE	! FL001
	P		SHORT PERIOD INSTRUMENT READ	
	L		LONG PERIOD INSTRUMENT READ,AMP. & 1ST MOTION DATA ONLY	
17-17	BLANK			! FL001
18-18		A1	PN WEIGHT	! FL001
	" "		USED IN CALCULATION	
	X		NOT USED IN CALCULATION	
19-19		A1	PN QUALITY DESIGNATOR	! FL001
	A		SHARP CLEAR BEGINNING (+- 0.25 SEC.)	
	B," "		GOOD BEGINNING (+- 1.0 SEC.)	
	C		WEAK POOR BEGINNING (+- 4.0 SEC. OR MORE)	
	X		PHASE NOT USED IN SOLUTION, LARGE RESIDUAL.	
	0		PHASE NOT READ	
20-21	14	I2	MINUTE OF PN ARRIVAL	! FL001
22-25	2341	F4.2	SECOND OF PN ARRIVAL	! FL001
26-28	CNW	3A1	FIRST MOTION OF PN ARRIVAL	! FL001
29-33	+0.03	F5.0??	TIME CORRECTION	! FL001
34-34		A1	PG WEIGHT	! FL001
	" "		USED IN CALCULATION	
	X		NOT USED IN CALCULATION	
35-35	A,B..	A1	PG QUALITY DESIGNATOR, SEE 19	! FL001
36-37	14	I2	MINUTE OF PG ARRIVAL	! FL001
38-41	264	F4.2	SECOND OF PG ARRIVAL	! FL001
42-44	DSE	3A1	FIRST MOTION OF PG ARRIVAL	! FL001
45-45		A1	SN WEIGHT	! FL001
	" "		USED IN CALCULATION	
	X		NOT USED IN CALCULATION	
46-46	A,B...	A1	SN QUALITY DESIGNATOR, SEE 19	! FL001
47-48	14	I2	MINUTE OF SN ARRIVAL	! FL001
49-52	52	F4.2	SECOND OF SN ARRIVAL	! FL001
53-53		A1	LG WEIGHT	! FL001
	" "		USED IN CALCULATION	
	X		NOT USED IN CALCULATION	
54-54	A,B...	A1	LG QUALITY DESIGNATOR, SEE 19	! FL001
55-56	14	I2	MINUTE OF LG ARRIVAL	! FL001
57-60	589	F4.2	SECOND OF LG ARRIVAL	! FL001
61-61	BLANK			! FL001
62-64	031	F3.2	PERIOD OF MAX. TRACE AMPLITUDE, SEC.	! FL001
65-68	150	F4.0	MAGNIFICATION OF INSTRUMENT AT GIVEN PERIOD, IN 1000.	
69-72	125	F4.1	TRACE AMPLITUDE (ONE-HALF MAX. PEAK-TO-PEAK) IN MM	
73-73	BLANK			! FL001
74-77		I4	DURATION IN SECONDS.	! FL001
78-79	BLANK			! FL001
80-80		I1	MAGNITUDE CODE	! FL001
	BLANK		AMPLITUDE SUITABLE FOR NUTTLI OR RICHTER SCALE	
	1		AMPLITUDE SUITABLE FOR RICHTER ONLY; CORDILLERN PATH	
	2		AMPLITUDE SUITABLE FOR EBEL	
	3		AMPLITUDE UNRELIABLE, NOT USED FOR MAGNITUDE	
	4		AMPLITUDE SUITABLE FOR HUEM & KISCO	
	5		AMPLITUDE SUITABLE FOR MS SCALE ONLY	
	8		SN AMPLITUDE READ, USE RICHTER SCALE ONLY BEYOND 600 KM IF REQUIRED	
81-83	BLANK			! FL001
84-85	15	I2	MINUTE OF THE MAX. AMPLITUDE	! FL001
86-89	155	F4.2	SECONDS OF THE MAX. AMPLITUDE	! FL001

```
<   FORMAT(A5,5I2,A1,1X,2A1,I2,F4.2,A3,F5.0,2A1,I2,F4.2,A3,2A1>
<   &      I2,F4.2,2A1,I2,F4.2,1X,F3.2,F4.0,F4.1,1X,I4,2X,I1,
<   &      3X,I2,F4,2)
```

CALCULATED DATA RECORD (CDR)

COLS	ENTRY	FORMAT	DEFINITION	
1-5	OTT	A3	STATION CODE	! FL001
6-6	BLANK			
7-8	NW	A2	QUADRANT OF STATION	
9-9	BLANK			
10-13	1305	I4	EPICENTRAL DISTANCE, KM	
14-15	KM	A2	RECORD FLAG	
16-16	BLANK			
17-18	28	F2.1	PN WEIGHT USED FOR CALCULATIONS	! FL001
19-23	0107	F5.2	PN RESIDUAL, SECOND	! FL001
24-24	BLANK,#	A1	LARGE RESIDUAL FLAG	! FL001
25-27	235	I3	AZIMUTH TO STATION, DEGREES	
28-30	049	I3	EMERGENT ANGLE	
			PN POSITIVE	

```
                          PG NEGATIVE
31-34 BLANKS
35-36 14        F2.1      PG WEIGHT                         ! FL001
37-41 -091      F5.2      PG RESIDUAL, SECOND               ! FL001
42-42 BLANK,#  A1        LARGE RESIDUAL FLAG               ! FL001
43-45 BLANKS
46-47 07        F2.1      SN WEIGHT                         ! FL001
48-52 0024      F5.2      SN RESIDUAL, SECOND               ! FL001
53-53 BLANK,#  A1        LARGE RESIDUAL FLAG               ! FL001
54-55 07        F2.1      SG WEIGHT                         ! FL001
56-60 -434      F5.2      SG RESIDUAL, SECOND               ! FL001
61-61 BLANK,#  A1        LARGE RESIDUAL FLAG               ! FL001
62-63 BLANKS
64-70 0001356   I7        GROUND VELOCITY, NM/SEC
71-71 BLANK
72-73 35        F2.1      RICHTER OR SURFACE WAVE MAGNITUDE
74-75 ML,MS     A2        MAGNITUDE DESIGNATOR
76-77 34        F2.1      NUTTLI MAGNITUDE
78-79 MN        A2        MAGNITUDE DESIGNATOR


<     FORMAT(A5,1X,A2,1X,I4.4,'KM',1X,F2.1,F5.2,A1,2I3.3,>
<     &         4X,F2.1,F5.2,A1,3X,F2.1,F5.2,A1,F2.1,        >
<     &         F5.2,A1,2X,I7.7,1X,2(F2.1,A2))             >
```