

GL-TR-90-0169

The M_L Scale in Norway

A. Alsaker
L. B. Kvanne
R. A. Hansen
A. Dahle
H. Bungum

NTNF/NORSAR
Post Box 51
N-2007 Kjeller, NORWAY

31 May 1990

Scientific Report No. 5

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

DTIC
ELECTE
SEP 27 1990
S C B D

GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AIR FORCE BASE, MASSACHUSETTS 01731-5000

AD-A226 859

SPONSORED BY
Defense Advanced Research Projects Agency
Nuclear Monitoring Research Office
ARPA ORDER NO 5307

MONITORED BY
Geophysics Laboratory
AFOSR F49620-89-C-0038

The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Defense Advanced Research Projects Agency or the U.S. Government.

This technical report has been reviewed and is approved for publication.


JAMES F. LEWKOWICZ
Contract Manager
Solid Earth Geophysics Branch
Earth Sciences Division


JAMES F. LEWKOWICZ
Branch Chief
Solid Earth Geophysics Branch
Earth Sciences Division

FOR THE COMMANDER


DONALD H. ECKHARDT, Director
Earth Sciences Division

This report has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

If your address has changed, or if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify GL/IMA, Hanscom AFB, MA 01731-5000. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document requires that it be returned.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; Distribution unlimited		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S)			5. MONITORING ORGANIZATION REPORT NUMBER(S) GI-TR-90-0169		
6a. NAME OF PERFORMING ORGANIZATION NTNF/NORSAR	6b. OFFICE SYMBOL (if applicable)	7a. NAME OF MONITORING ORGANIZATION Geophysics Laboratory			
6c. ADDRESS (City, State, and ZIP Code) Post Box 51 N-2007 Kjeller, Norway			7b. ADDRESS (City, State, and ZIP Code) Hanscom Air Force Base Massachusetts 01731-5000		
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Defence Advanced Research Projects Agency	8b. OFFICE SYMBOL (if applicable) NMRO	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER Contract No. F49620-89-C-0038			
8c. ADDRESS (City, State, and ZIP Code) 1400 Wilson Blvd. Arlington, VA 22209-2308			10. SOURCE OF FUNDING NUMBERS		
			PROGRAM ELEMENT NO. 62714E	PROJECT NO. 9A10	TASK NO. DA
			WORK UNIT ACCESSION NO. BH		
11. TITLE (Include Security Classification) The M_L scale in Norway					
12. PERSONAL AUTHOR(S) A. Alsaker, L.B. Kvamme, R.A. Hansen, A. Dahle and H. Bungum					
13a. TYPE OF REPORT SCIENTIFIC REP. #5	13b. TIME COVERED FROM 90/02/98 90/04/30	14. DATE OF REPORT (Year, Month, Day) 1990 May 31		15. PAGE COUNT 70	
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	M_L magnitude scale for Norway, Lg waves, Lg blockage, regression analysis		
19. ABSTRACT (Continue on reverse if necessary and identify by block number)					
A new local magnitude M_L scale has been developed for Norway, based on a regression analysis of synthesized Wood-Anderson records. The scale is applicable for distances up to more than 1000 km, and the data used comprise 741 short-period recordings at 21 seismic stations from 195 earthquakes in the magnitude range 1 to 5 occurring in and around Norway over the last 20 years. Magnitude corrections for distance have been evaluated in terms of a geometrical spreading term a and an anelastic attenuation term b, and the significant regional crustal differences in the area under investigation made it desirable to develop these for several subsets of the data base. The results for a are generally found to be around the commonly found value of 1.0 (using the L_g phase), while the b-values are found to be around 0.0008, consistent with the weak, intraplate attenuation expected for Norway. Compared to interplate California, this difference in attenuation represents more than one magnitude unit at a distance of 1000 km.					
20. DISTRIBUTION AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED		
22a. NAME OF RESPONSIBLE INDIVIDUAL James Lewkowicz			22b. TELEPHONE (Include Area Code) (617) 377-3028	22c. OFFICE SYMBOL GL/LWH	

New M_L scales are commonly tied to Richter's original definition at the standard reference hypocentral distance of 100 km. The significantly weaker L_g wave attenuation in Norway, however, requires a smaller reference distance. We have chosen a value of 60 km, based on an overall assessment of regional coverage, focal depths and quality of the data. The resulting M_L formula for Norway reads

$$M_L = \log A_{wa} + a \log(R/60) + b (R - 60) + 2.68 + s$$

where A_{wa} is synthesized Wood-Anderson amplitude (in mm), R is hypocentral distance (in km), and s is a station correction term that for all 21 stations is found to lie within the range ± 0.22 . When using the entire data base the spreading term a equals 1.02, and the anelastic attenuation term b equals 0.00080. When only strictly continental ray paths are selected, the a -value decreases to 0.91 while the b -value increases to 0.00087, a difference which on the average accounts for less than 0.1 magnitude units. While all values used in the regressions have been derived for vertical amplitudes, a separate analysis has shown that these are not significantly different from the horizontal ones, and the new scale is therefore applicable to both. In order to facilitate the practical use of this new M_L scale, a relation has also been established between observed seismogram amplitudes (corrected for instrument response) and the synthesized Wood-Anderson amplitudes. This relation reads $\log A_{wa} = 0.925 \log A_{obs} - 2.32$.

The new M_L magnitudes for the events analyzed are in fairly good agreement with those calculated from a previously used relation developed by Båth for Sweden. The new values are, however, systematically about 0.4 magnitude units lower, which is mostly due to the combined effect of a reference distance less than 100 km and a Wood-Anderson magnification of 2080 instead of the earlier value of 2800. The new M_L values have also regressively been related to a data set of M_S values, yielding the relation $M_S = 0.83M_L + 1.09$.



Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

Preface

Under Contract No. F49620-C-89-0038, NTNF/NORSAR is conducting research within a wide range of subjects relevant to seismic monitoring. The emphasis of the research program is on developing and assessing methods for processing of data recorded by networks of small-aperture arrays and 3-component stations, for events both at regional and teleseismic distances. In addition, more general seismological research topics are addressed.

Each quarterly technical report under this contract presents one or several separate investigations addressing specific problems within the scope of the statement of work. Summaries of the research efforts within the program as a whole are given in annual technical reports.

This Scientific Report No. 5 presents a manuscript entitled "The ML scale in Norway", by A. Alsaker, L.B. Kvamme, R.A. Hansen, A. Dahle, and H. Bungum.

THE M_L SCALE IN NORWAY

by

A. ALSAKER, L.B. KVAMME, R.A. HANSEN, A. DAHLE, AND H. BUNGUM

ABSTRACT

A new local magnitude M_L scale has been developed for Norway, based on a regression analysis of synthesized Wood-Anderson records. The scale is applicable for distances up to more than 1000 km, and the data used comprise 741 short-period recordings at 21 seismic stations from 195 earthquakes in the magnitude range 1 to 5 occurring in and around Norway over the last 20 years. Magnitude corrections for distance have been evaluated in terms of a geometrical spreading term a and an anelastic attenuation term b , and the significant regional crustal differences in the area under investigation made it desirable to develop these for several subsets of the data base. The results for a are generally found to be around the commonly found value of 1.0 (using the L_g phase), while the b -values are found to be around 0.0008, consistent with the weak, intraplate attenuation expected for Norway. Compared to interplate California, this difference in attenuation represents more than one magnitude unit at a distance of 1000 km.

New M_L scales are commonly tied to Richter's original definition at the standard reference hypocentral distance of 100 km. The significantly weaker L_g wave attenuation in Norway, however, requires a smaller reference distance. We have chosen a value of 60 km, based on an overall assessment of regional coverage, focal depths and quality of the data. The resulting M_L formula for Norway reads

$$M_L = \log A_{wa} + a \log(R/60) + b(R - 60) + 2.68 + S$$

where A_{wa} is synthesized Wood-Anderson amplitude (in mm), R is hypocentral distance (in km), and S is a station correction term that for all 21 stations is found to lie within the range ± 0.22 . When using the entire data base the spreading term a equals 1.02, and the anelastic attenuation term b equals 0.00080. When only strictly continental ray paths are selected, the a -value decreases to 0.91 while the b -value increases to 0.00087, a difference which on the average accounts for less than 0.1 magnitude units. While all values used in the regressions have been derived for vertical amplitudes, a separate analysis has shown that these are not significantly different from the horizontal ones, and the new scale is therefore applicable to both. In order to facilitate the practical use of this new M_L scale, a relation has also been established between observed seismogram amplitudes (corrected for instrument response) and the synthesized Wood-Anderson amplitudes. This relation reads $\log A_{wa} = 0.925 \log A_{obs} - 2.32$.

The new M_L magnitudes for the events analyzed are in fairly good agreement with those calculated from a previously used relation developed by Båth for Sweden. The new values are, however, systematically about 0.4 magnitude units lower, which

is mostly due to the combined effect of a reference distance less than 100 km and a Wood-Anderson magnification of 2080 instead of the earlier value of 2800. The new M_L values have also regressively been related to a data set of M_S values, yielding the relation $M_S = 0.83M_L + 1.09$.

INTRODUCTION

The emergence in everyday seismological practice of concepts such as seismic moment, which relates in a well-defined way to energy release, or the "size" of earthquakes, has not reduced the importance of the magnitude concept as developed originally by Richter (1935). A large number of magnitude scales have been developed since then (e.g. Båth, 1981), and most of them are similar to Richter's scale in the sense that they are based on the logarithm of some amplitude measurement. Most of them are also not related in any well-defined way to the energy release. What is important then is consistency, in time as well as in space. For magnitudes such as m_b and M_S , the spatial consistency is taken care of through the use of globally adopted formulas, based on the fact that the attenuation of teleseismic P -waves and 20 sec period S -waves are only moderately affected by local geological conditions. Local conditions show up in these cases only through the possible use of station corrections.

For the local magnitude M_L , based on maximum L_g amplitudes at local and regional distances, a similar use of common distance (attenuation) correction terms would distort rather than secure this consistency. The reason is that the wave attenuation in this case is more dependent upon local geological conditions, especially those relating to different tectonic regimes (in particular transitions between plate margin and intraplate areas). In order for M_L magnitudes to be consistent, the seismic wave attenuation within each region must be determined, and the magnitude relations for the different regions tied together at a near-source reference distance. In addition, local site conditions leading to amplification or deamplification of the measured ground motions are commonly accounted for in terms of station corrections.

For regional distances, the M_L scale is most important simply because it provides the best consistency, stability and measurability. The importance of regional seismology has moreover increased steadily in recent years, as related to societal needs connected to nuclear explosion monitoring, emergency and disaster prevention, building codes, engineering design criteria, insurance, and safety aspects in general.

In Norway, M_L magnitudes were not routinely reported until Båth *et al.* (1976) developed a new local magnitude scale (hereafter for simplicity called Båth's M_L scale) based on Swedish data. The scale was based on Richter's definition with a reference distance of 100 km, and with the analog data used in the development it was found necessary to introduce frequency dependent correction factors. When applying Båth's M_L formula to digitally recorded data it soon became evident that these correction factors were inadequate, but we nevertheless continued to use this scale in Norway in order to maintain consistency until more appropriate and reliable correction terms could be developed.

The purpose of the present paper is to develop such correction terms, and thereby contribute to the establishing of a new M_L scale for Norway. Since the NORSAR

array was installed in Norway around 1970, the amount of reliable digital earthquake recordings has increased steadily, not only due to the time factor itself but also because the number of seismic stations is increasing. This development is best illustrated by the fact that data from 21 seismic stations located in Norway have been used in the present study.

METHOD OF ANALYSIS

In following Richter (1935; 1958), the local magnitude M_L is defined as

$$M_L = \log A - \log A_0 + S \quad (1)$$

where A is measured amplitude (zero-to-peak) in mm on a horizontal component Wood-Anderson seismometer recording, S is a station correction term, and $-\log A_0$ is a distance correction term given as

$$-\log A_0 = a \log(R/100) + b(R - 100) + 3.0 \quad (2)$$

where a and b are coefficients for geometrical spreading and anelastic attenuation, respectively, and R is hypocentral distance.

With no station correction, equations (1) and (2) imply that an earthquake which is observed with an amplitude A of 1 mm at a distance of 100 km in Southern California is given a magnitude M_L of 3.0. In developing the first set of A_0 values, from a small data base of Wood-Anderson seismometer recordings from southern California, Richter (1935) did not separate the two attenuation terms as in equation (2). Recently, from very large data bases, Bakun and Joyner (1984) and Hutton and Boore (1987) have developed new attenuation terms for central and southern California, respectively, in surprisingly good agreement with Richter's values. The only exception here is for near-source distances, where Richter's coverage was poorer, especially in terms of focal depths. Because of this, we will replace Richter's attenuation values with those of Hutton and Boore (1987).

In a more general form, equation (2) reads

$$-\log A_0 = a \cdot \log(R/R_{ref}) + b \cdot (R - R_{ref}) + K(R_{ref}) \quad (3)$$

where R_{ref} is a reference distance that could be different from 100 km, and $K(R_{ref})$ is a constant to be defined below.

To establish the new magnitude scale, we combine equations (1) and (3) to give

$$\log A_{ij} = -a \log(R_{ij}/R_{ref}) - b(R_{ij} - R_{ref}) - \sum_{k=1}^{N_e} M_k \delta_{ik} + \sum_{l=1}^{N_s} S_l \delta_{lj} - K(R_{ref}) \quad (4)$$

where A_{ij} is the amplitude of earthquake i at station j , R_{ij} is hypocentral distance for earthquake i at station j , δ_{ij} is the Kronecker delta (1 if i equals j , otherwise 0), N_s is number of stations, and N_e is number of events.

The parameters to be determined regressively are a , b , M_k and S_l , representing the geometrical spreading, anelastic attenuation, magnitude, and station correction respectively. Equation (4) can be rewritten in matrix form as:

$$\begin{pmatrix} 1 & 0 & 0 & \dots & 0 & 1 & 0 & 0 & \dots & 0 & r_{11} & u_{11} \\ 1 & 0 & 0 & \dots & 0 & 0 & 1 & 0 & \dots & 0 & r_{12} & u_{12} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 1 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & \dots & 1 & r_{1N_s} & u_{1N_s} \\ 0 & 1 & 0 & \dots & 0 & 1 & 0 & 0 & \dots & 0 & r_{21} & u_{21} \\ 0 & 1 & 0 & \dots & 0 & 0 & 1 & 0 & \dots & 0 & r_{22} & u_{22} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & \dots & 1 & 0 & 0 & 0 & \dots & 1 & r_{N_e N_s} & u_{N_e N_s} \end{pmatrix} \cdot \begin{pmatrix} M_1 \\ \vdots \\ M_{N_e} \\ S_1 \\ \vdots \\ S_{N_s} \\ -a \\ -b \end{pmatrix} = \begin{pmatrix} y_{11} \\ y_{12} \\ \vdots \\ y_{1N_s} \\ y_{21} \\ y_{22} \\ \vdots \\ y_{N_e N_s} \end{pmatrix} \quad (5)$$

or $\mathbf{Ax} = \mathbf{y}$ which is a system of at least $N_e + N_s + 2$ linearly independent equations. In equation (5) $r_{ij} = \log(R_{ij}/R_{ref})$, $u_{ij} = (R_{ij} - R_{ref})$, and $y_{ij} = \log A_{ij} + K(R_{ref})$.

The vector of unknowns ($\mathbf{x}$) can be found by inversion of $\mathbf{A}$, under the constraint that the station corrections sum to zero ($\sum_{k=1}^{N_s} S_k = 0$). The regression coefficients a (geometrical spreading) and b (anelastic attenuation) determine the form of the $-\log A_0$ curve in accordance with equation (3). The connection to Richter's M_L definition is achieved as explained above by anchoring our $-\log A_0$ values to those of Hutton and Boore (1987), resulting in the following relation

$$K(R_{ref}) = 1.110 \log(R_{ref}/100) + 0.00189(R_{ref} - 100) + 3.0 \quad (6)$$

which is seen to give a value of 2.0 for 17 km (as suggested by Hutton and Boore) and 3.0 for a distance of 100 km (as used by Båth). At the reference (anchoring) distance, the same amplitude will correspond to the same magnitude in Norway and California. We return below to the question of selecting an appropriate value for $K(R_{ref})$ for this study.

DATA

The earthquake recordings used in this study are listed in Appendix 1, comprising altogether 741 records from 21 stations and 195 earthquakes occurring in and around Norway between 1971 and 1989. The epicentral distances covered are in the range 20 to 1600 km. Stations and epicenters are shown in Figure 1, resulting in a ray path pattern covering the entire Norway and adjacent areas. The stations are also listed separately in Table 1, together with the number of records from each station and the station corrections resulting from the inversion of one particular subset of the data.

Originally, a much larger data base was considered, based on available earthquake catalogues since 1971 (Bungum *et al.*, 1990). In doing this, we identified essentially all events with a reasonable possibility for providing records above the noise level for at least one digitally recording seismic station, which resulted in a range of magnitudes between 1 and 5. That information was then combined with information about the

time periods of recording for the different stations in Norway (Havskov *et al.*, 1990), which reduced the number of possibly useful records.

For each event selected, expected arrival times for the different regional phases were calculated from standard travel time tables. A desired data interval was then computed, covering a time window from 30 sec before the first P-arrival (to provide noise estimates) to 30 sec after the time corresponding to a group-velocity of 1.8 km/s (to provide data for Q-studies). The selected data intervals were then extracted from offline storage media and loaded into a computer data base in a common, compact and easily readable format. During this process all available digital data were included, without any further check on quality and usefulness. This provided more than 1000 records from more than 200 earthquakes.

The subsequent interactive analysis, to be described in more detail below, included also a quality screening through which clipped and noisy recordings were identified and excluded. Recordings containing interfering events were also excluded at this stage. This resulted in the 741 records mentioned above, ready for the subsequent M_L analysis. All of these records are from vertical components, and only a limited number of these are from stations that also provide horizontal component records.

The distribution of the selected data in magnitude-distance space is shown in Figure 2. One unavoidable characteristic of such distributions is that small earthquakes are more often recorded at shorter distances, while larger earthquakes generally have more distant recordings. This trend is amplified if the dynamic range of the sensors is small, leading to clipping of strong ground motions and poor signal-to-noise ratios for weak motions. It is desirable to work with data sets with a lowest possible correlation between magnitude and distance (Joyner and Boore, 1981; Dahle *et al.*, 1990). The data shown in Figure 2 have a correlation coefficient between magnitude and distance of 0.46.

DATA ANALYSIS

In following the methodological approach outlined above, we analyzed the selected data as follows: (1) convert each (vertical) record into a synthesized Wood-Anderson (SWA) seismogram, and read the maximum zero-to-peak amplitudes of the S -wave train (normally L_g), (2) evaluate from independent data the ratio between horizontal and vertical motion for the purpose of compensating for this effect (real WA seismograms are all horizontal), (3) select a reference distance for connecting to Richter's M_L definition, (4) read the maximum S -wave (L_g) amplitudes from the original uncorrected seismograms, and then convert to ground motion, and (5) perform a linear regression analysis as outlined above. Even though points (2) and (3) do not influence the determination of the attenuation terms, they are still necessary for establishing the resulting M_L formula. Point (4) is needed for facilitating the use of amplitudes from uncorrected seismograms, and in particular analog records.

In the following we will cover each of these points in more detail.

Synthesized Wood-Anderson seismograms

The main problem in creating the SWA records is the fact that the WA torsion seismographs are more broad band than the mostly short-period seismometers (velocity transducers) used in recording our data. Since the deconvolution of the instrument response and the convolution with the WA response is performed in the frequency domain, a proper prefiltering reflecting the frequency limitations of the recording systems becomes very important in order to avoid instabilities. For the regional microearthquake networks in southern, western and northern Norway (recording at 50 Hz) we have used a passband of 0.8 - 20 Hz, for the regional arrays NORESS and ARCESS (recording at 40 Hz) 0.8 - 15 Hz, for NORSAR (recording at 20 Hz but with an anti-aliasing filter at 5 Hz) 0.2 - 5 Hz, and for the NORESS intermediate-period (broad band) data (recording at 10 Hz) we have used a filter at 0.02 - 2 Hz. Table 1 shows the number of records used from each of these systems.

In addition to synthesizing WA seismograms, which was done interactively in order to secure the highest possible quality, a considerable effort was also invested in acquiring the right system response functions (in complex form). Because of frequent changes for some of the stations, this involved keeping several hundred different response functions on file. Of similar importance of course is the Wood-Anderson response, where the frequency response is simple and well known (natural period 0.8 sec, damping ratio 0.8). It has been known for some time, however, that the static magnification of the WA seismographs probably is lower than the theoretical value of 2800 (Bakun and Lindh, 1977; Luco, 1982; Hutton and Boore, 1987; Boore, 1989). Convincing evidence in this respect has now been forwarded by Urhammer and Collins (1990), showing that the magnification of the Wood-Anderson seismographs is 2080 rather than 2800 and that the proper damping ratio is 0.7 rather than 0.8. We have, in accordance with this finding, used a magnification of 2080 and damping ratio of 0.7 when creating our SWA records, yielding magnitudes 0.13 units below those obtained with the earlier value.

The reading of the maximum amplitudes (zero-to-peak) of the seismograms is both simple and reliable when done interactively (manually) in the way it was done in this study. Naturally, both the time and period of the maximum wave of the SWA seismograms, in some cases, can be quite different from what would appear on the uncorrected records.

Horizontal vs. vertical motions

The recording capability for the majority of stations contributing to this study is limited to vertical component recording. Realizing that the original *Richter* (1935; 1958) definition of M_L is for horizontal components of motion, the strategy for this study was to obtain the horizontal to vertical component relationship in a separate analysis for stations where both components are available. The vertical amplitudes should then be corrected according to this relationship by assuming (preferably) a constant correction factor, thus providing regression results for the horizontal component as required.

To this end, we compared amplitudes of vertical and horizontal components for the available three-component seismograms. A total number of 126 three-component recordings from 100 events for the stations NAO, NRA0, ARA0 and LOF were avail-

able for this. For each three component record we computed the fraction

$$F_{h,v} = \frac{0.5(\log A_{ns} + \log A_{ew})}{\log A_z} \quad (7)$$

where A_{ns} and A_{ew} are amplitudes from the two horizontal components and A_z from the vertical component. A plot of the data points is shown in Figure 3, demonstrating in fact that the difference in size between horizontal and vertical components in this case is insignificant. The mean value of the ratio is 1.008 and the correlation coefficient is 0.99. In accordance with this, the vertical amplitudes are used in our study as if they were horizontal.

Reference distance

We have already introduced the concept of the reference distance in equations (3) and (4), and indicated that a value of 100 km would be inappropriate because of the significant regional differences in attenuation between Norway and Southern California at that distance. The solution to this problem is of course to choose a distance that is small enough to ensure that earthquakes with similar energy release will create the same size ground motions (as measured on a WA seismograph) in the two regions. That may sound simple, but it is not.

The first condition that must be fulfilled in this respect is that near-source ground motions are comparable for wave propagation through the late Cenozoic rock formations in California and the Precambrian and Paleozoic rocks in Norway. Campbell (1989) has recently published evidence in support of this, finding that for earthquakes in the same magnitude range as ours, the near-source accelerations in eastern North America are consistent with predictions based on Californian observations, once site effects and differences in magnitude scales are accounted for.

A second condition is that Richter's A_0 values are sufficiently reliable at hypocentral distances of less than 100 km. That is probably not the case, but we can solve this problem (as already mentioned) by using the more reliable values of Hutton and Boore (1987). Using their A_0 values, which are identical to Richter's at a distance of 100 km, a magnitude 3.0 earthquake should be recorded with an amplitude of 10 mm at a reference distance (R_{ref}) of 17 km. Hutton and Boore recommended this value be used in a situation like ours, securing a sufficient near-source anchoring.

A third condition, however, is that our local attenuation function can be evaluated with sufficient precision down to the suggested reference distance. If this is not the case, a larger R_{ref} should be chosen. Our average depth of 16 km of course immediately precludes using any reference distance less than about 30 km. Essential here is our distribution of hypocentral distances (see Figure 2), showing only 3 records within 20 - 40 km, 6 within 40 - 60, 10 within 60 - 80, and 10 within 80-100 km. We have consequently selected a R_{ref} value of 60 km, balancing the requirement of a near-source reference distance with data quality considerations.

Using this reference distance of 60 km, the resulting A_0 curves (as taken from the regression analysis discussed below) for focal depths of 0 and 20 km are shown in Figure 4 (solid lines), along with those of Hutton and Boore (1987) for comparison (dashed lines). It is seen there that the difference between the $-\log A_0$ curves never

exceeds 0.15 magnitude unit for any distance within 100 km (note that they are plotted vs. *epicentral* distance). For larger distances the difference in anelastic attenuation (b values) results of course in divergence of the curves, and a difference on the order of one magnitude unit at a distance of 870 km. From equation (6) we see that $K(R_{ref})$ obtained for $R_{ref} = 60$ km is 2.68.

Given these similarities in the near field, the main uncertainty with respect to the anchoring is therefore not tied to the determination of R_{ref} but rather to the underlying assumption of near-source ground motion equivalence.

Regression analysis

Using the entire data base of 741 seismograms from 195 earthquakes, a linear regression analysis was performed as outlined above. However, since earthquakes with less than two recordings do not contribute in the estimation of a and b in equation (4), we chose to use only events with a minimum of 3 recordings to also help with azimuthal averaging. The effective size of the data base then reduces to 624 seismograms from 120 earthquakes.

Even though epicenter estimates are available for our events with a sufficient precision (generally within ± 5 -15 km), focal depths are not available for the majority of them. We know, however, the focal depth distribution fairly well in the region (Bungum *et al.*, 1990), and on this basis we chose to use a value of 16 km for all of the events when estimating hypocentral distances for the regression. This factor is of course of importance only for the closest epicentral distances, and separate tests have shown that the effect is marginal within the range of realistic focal depths.

The results of this inversion for different subsets are discussed below and values for a and b are given in Table 2. While a -values like these are commonly found, such low b -values are possible only in truly intraplate, high- Q areas (Kvamme and Havskov, 1989; Dahle *et al.*, 1990). The southern California value of Hutton and Boore (1987), in comparison, is 0.00189, and the central California value of Bakun and Joyner (1984) is 0.00301.

Individual station corrections constrained to have zero average are estimated during the M_L regression, and given with standard deviations in Table 1. The station corrections are all in the range -0.21 to +0.22 magnitude units, and with a standard deviation which varies from 0.05 to 0.10. The variation in the standard deviation is probably attributable to the difference in the number of events recorded at the different stations.

Amplitudes from observed (uncorrected) seismograms

The computation of synthesized Wood-Anderson amplitudes is not feasible in all routine magnitude assessments, in particular when analog records are considered. We have therefore also measured the maximum (L_g) amplitudes (and periods) on the observed (raw) seismograms, and corrected these amplitudes for system response. Note that this is different from measuring amplitudes from response corrected (ground motion) seismograms, which should be expected to give values (ignoring gain differences) closer to the WA seismograms.

The "observed" amplitudes are shown in Figure 5 together with the SWA ampli-

tudes. A maximum likelihood regression analysis (assuming the same size errors in the two axes) gives the following relation

$$\log A_{wa} = 0.925 \cdot \log A_{obs} - 2.32 \quad (8)$$

where A_{wa} is the SWA amplitude and A_{obs} is the response corrected ground motion amplitude in nanometers.

This regression is quite reliable and therefore very useful for adapting our M_L relations to situations when SWA seismograms cannot easily be obtained. The systematic difference between the two amplitudes is due to the fact that the SWA amplitudes are often picked for waves with longer periods thereby yielding larger ground motion amplitudes.

It should be noted here, however, that one factor contributing to the small scatter in Figure 5 is the fact that most of the data are taken from recording systems that have reasonably similar (short period) response characteristics. Equation (10) below is therefore not necessarily applicable to other systems.

REGIONAL VARIATIONS

As can be seen on Figure 1, some ray paths extend into offshore regions, entering geologic features such as the Viking Graben in the North Sea, and crossing the continental margin along the entire western and northern coastline of Norway (Hansen *et al.*, 1989; Bungum *et al.*, 1990). The propagation of L_g waves across such strong variations in the crustal waveguide usually results in a strong deterioration of the L_g phase (Kennett *et al.*, 1985; Regan and Harkrider, 1989; Bostock and Kennett, 1990). The continental margin areas, and the graben structures of the North Sea represent such varying conditions for L_g propagation, resulting in some instances in a blockage of the L_g waves strong enough to make the S_n phase the strongest one in the seismogram.

For this reason, and also because we wanted to see if significant variations could be found within the more strictly continental areas, we inverted our data for a number of subsets as shown in Table 2. Results are presented there for (1) all data, (2) continental paths only, (3) distances less than 1000 km, (4) epicenters north of 63° N using all stations, (5) epicenters south of 63° N using all stations, (6) epicenters north of 63° N using only the northern stations, (7) epicenters south of 63° N using only the southern stations, and (8) readings with group velocities equal to or below 3.8 km/s. The number of (effectively contributing) observations in each of these cases are listed in the right hand column of Table 2.

For all subsets, the data were inverted with all parameters free, and for an a -value fixed to 1.0. The reason for this is that there is often a trade-off between the a - and the b -values estimated in the regression. In keeping the a -values fixed it is then easier to judge the significance of the differences in the b -values as a function of regional variation in anelastic attenuation. Some more specific comments on the results in Table 2 are presented in the following.

The subset that should be expected to provide the best selection of more purely continental L_g paths is subset 2 in Table 2. The results indicate only a small difference as compared to the regression over the entire data base. This difference in fact illustrates the trade-off between the a -value (spreading) and the b -value (anelastic attenuation). The resulting values are only marginally outside the estimated error limits. The value estimated for a is actually closer in this case to the theoretical value of 0.83 expected for an Airy (L_g) phase. However, the resulting differences in the $-\log A_0$ term amount to less than 0.1 magnitude units at any distance. Similar results are obtained for subset 3, with epicenter distances less than 1000 km, which serves to exclude some of the distant events located in oceanic crust. For a fixed a -value, Table 2 shows a slight increase in b from subset 2, probably because some of the ray paths are sampling more offshore areas.

Subsets 4-7 were created to look for possible regional differences with respect to the northern and the southern areas (see Figure 1). When considering the increasing uncertainties (due to decreasing data sets), there is no basis for suggesting different a and b values for different regions.

The final test (subset 8) include data sorted on apparent group velocity for the maximum amplitude arrivals of the recordings. This kind of sorting should make it possible to exclude some of the situations in which S_n (or S_g) dominates the seismogram instead of L_g , which normally has a group-velocity of around 3.5 km/s. For subset 8 we have therefore selected records with group-velocities of $\beta \leq 3.8$ km/s. As can be seen from Table 2, this selection does not yield results significantly different from subsets 1 and 2, showing that S_n contamination is not seriously affecting our results.

RESULTING MAGNITUDE RELATION

Having now determined the $-\log A_0$ -values (in terms of a and b), the reference (anchoring) distance R_{ref} (60 km), and the horizontal to vertical ratio (1.0), a simple magnitude relation is obtained as:

$$M_L = \log A_{wa} + 0.91 \log(R) + 0.00087 (R) + 1.010 + S \quad (9)$$

where $R = \sqrt{\Delta^2 + h^2}$ is hypocentral distance, Δ is epicentral distance, h is source depth, and station corrections S can be found in Table 1. The a and b values are taken here from Table 2, subset 2, which provides more purely continental L_g travel paths. Equation (9) therefore does not apply correctly (neither would subset 1) to offshore travel paths subjected to L_g blockage, a problem which we will return to in the Discussion.

In Figure 6 we have plotted the derived L_g attenuation for Norway together with the Hutton and Boore (1987) relation for southern California, and up to a larger distance than shown in Figure 4. The data points plotted are our SWA readings corrected for the M_L and S terms in equation (4) using equation (9), and show the distribution of all observations about the $-\log A_0$ curve according to equation (3). The curve and the points clearly show the difference in attenuation in southern Californian

as opposed to that of L_g phases in Norway, a difference which amounts to one full magnitude unit at a distance of 870 km and 1.7 units at 1500 km.

The regression of logarithmic SWA amplitudes provides, in addition to attenuation and station corrections, new estimates of the magnitudes for all of the events in the data set. The largest of these, with M_L above 3.5, are listed separately in Table 4 together with their epicentral locations.

The residuals in the regression of the SWA amplitudes are essentially magnitude residuals, as may be deduced from equation (1). The residual distributions versus epicentral distance and regressed magnitude, respectively, are shown in Figures 7a and 7b. The dotted lines indicate standard deviations of about 0.17, and the plots show no particular trend with respect to distance or magnitude.

When replacing the SWA amplitudes (A_{wa}) with gain-corrected amplitudes from observed (raw) seismograms (A_{obs}) in nanometers by combining equations (8) and (9), the following relation is obtained:

$$M_L = 0.925 \log A_{obs} + 0.91 \log(R) + 0.00087 (R) - 1.310 + S \quad (10)$$

DISCUSSION

One of the limitations in the present work is that to a large extent we use short period data (with cutoffs as high as 0.8 Hz) for synthesizing the Wood-Anderson seismograms. This could, in particular at shorter distances and for larger events, lead to some underestimation of the SWA amplitudes and thereby to a negative bias in the resulting magnitudes. However, since the largest earthquake in our data base is only M_L 5.0, we expect this effect to be modest.

The stability of our analyses with the different subsets tested above reflects quite positively on our results with respect to their usefulness and applicability. An essential factor behind the stability is of course the good distribution of both stations and epicenters, yielding a good coverage in magnitude and distance (taking into account that this is a low-to-intermediate seismicity region). In addition, our data ensures a good azimuthal coverage, which is quite important with respect to averaging of path (tectonic) as well as source (radiation pattern) effects.

We interpret, however, this stability first of all as a reflection of the fact that our analysis essentially is resolving attenuation characteristics *between* the seismic stations, and not between the epicenter and first station. For offshore epicenters and onshore stations we often sample only the continental parts of the path, except in the cases when several stations along the coast record an event at different epicentral distances. This effect creates a "continental bias" which can explain some of the observed stability, and the result is an underestimation of magnitudes for some of the offshore events. The problem of L_g blockage due to the crustal waveguide variations imposed by grabens and continental margins are consequently not resolved in the present study.

A proper assessment of local magnitudes (based on maximum amplitude within the S-wave train) for wavepaths crossing tectonic features that may cause L_g blockage

therefore requires an approach within which the transfer function for waves passing through such areas is established. Such an approach requires an independent assessment of the size of these earthquakes either through the use of teleseismic arrivals (usually not available for these events) or P_g/P_n arrivals, or by obtaining S -wave train observations (including both S_n and L_g) from both sides of the L_g blocking area. Data of such kind would make it possible to establish correction terms for source areas with L_g blockage problems, included as adjustments to our existing magnitude formula.

In the mean time, and in spite of the fact that L_g blockage has been firmly established as causing a reduction in the amplitude across a relatively short transition zone, the local magnitude formula to be adopted for observatory practice in Norway would have to be one based on travel paths propagating essentially within the continental crust. Hopefully, corrections for some of the offshore paths will be available later.

Up to now, we have used as mentioned earlier Båth's relation for M_L magnitudes in Norway. When using this relation on our raw data amplitudes we find that they are in fairly good agreement with our new SWA-based M_L values, as shown in Figure 8. It should be noted, however, that we have computed the Båth M_L values using a fixed period in order to avoid the instabilities (mentioned above) caused by the frequency sensitivity of Båth's relation. Therefore, when comparing with earlier reported magnitudes based on that relation, the scatter becomes much larger.

From Figure 8 we see that the Båth magnitudes are generally about 0.4 units higher than the new ones, an offset which can be explained by the combined effect of using a smaller anchoring distance than Båth (60 instead of 100 km) and a different value for the WA gain (2080 instead of 2800). When considering the fact that Båth *et al.* (1976) developed their relation exclusively from analog data, and when not considering the problems tied to the frequency dependence of the correction tables, we can therefore conclude now that their relation is impressively accurate.

The present study has to some extent been inspired by the need within the petroleum industry for reliable earthquake hazard estimates offshore Norway (Bungum and Selnes, 1988). Such estimates are largely based on M_S magnitudes obtained from historical data through a major reassessment of felt areas from earthquakes, and calibrated against M_S measurements from instrumental data (Muir Wood and Woo 1987). Within this context, and for other reasons as well, a reliable relation between this M_S scale and our new M_L values is therefore of much importance. For earthquakes down to magnitude 3.5, Figure 9 presents this magnitude comparison, with the data listed separately in Table 4. A maximum likelihood regression analysis of M_L versus M_S (assuming the same sized errors in both axes) resulted in the equation

$$M_S = 0.83 \cdot M_L + 1.09 \quad (11)$$

This result is in good agreement with the relation $M_S = 0.85 \cdot M_L + 0.60$ obtained earlier by Bungum (1987), using M_L magnitudes determined by the Båth formula. The difference of 0.5 in the constant coefficient is consistent with the mean difference between the new M_L scale and the Båth M_L scale discussed above.

CONCLUSIONS

Almost 20 years of digital data, comprising 741 records from 195 earthquakes in the magnitude range 1-5, have been used in developing a new M_L scale for Norway. The data base includes records from 21 stations, and cover distances from 20 to about 1500 km. We have converted all records (covering the maximum of the L_g wave train) to synthesized Wood-Anderson seismograms, and inverted for L_g wave attenuation (distance corrections), individual earthquake magnitudes, and station corrections. The attenuation has been developed in terms of Richter's $-\log A_0$ values, expressed through a geometrical spreading term a and an anelastic attenuation term b . We conclude that

(1) When using the entire data base, including also some wave paths affected by L_g blockage problems connected to offshore graben structures and the continental margin, we find an a -value of 1.02 and a b -value of 0.00080. A subset of more purely continental wave paths give values of 0.91 and 0.00087. Differences in magnitude computed from any of these two a and b value sets, are less than 0.1 magnitude units at any distance.

(2) Geometrical spreading terms (a -values) around 1.0 are commonly found in many different tectonic environments, while anelastic terms (b -values) as low as 0.0008 are specific for high- Q intraplate environments such as Norway. In comparison, b -values in California are typically 2-4 times larger, indicating the same (inverse) ratio with respect to average effective Q .

(3) Due to spatial sampling problems we have not in the present study been able to resolve satisfactorily the problems tied to L_g blockage for partially offshore wave paths. Some of the earthquakes occurring sufficiently far from the Norwegian coastline will therefore (still) be underestimated in magnitude when using our new M_L formula. Additional correction terms for these events will have to be developed later.

(4) When anchoring a new M_L scale to Richter's definition it is necessary to define a reference distance at which the same sized earthquake is assumed to produce the same ground motion, and with large differences in regional L_g wave attenuation a near-source reference distance is required. Because of limitations in our data at short distances we have in the present study set this reference distance to 60 km.

(5) Given this reference distance, the difference between the correction factors of Hutton and Boore (1987) for southern California and ours for Norway never exceeds 0.1 magnitude units for any distance within 100 km. At 870 km, however, the difference amounts to one full magnitude unit, and at 1500 km to 1.7 units.

(6) It has been known for a long time that the magnification of the Wood-Anderson seismograph probably is less than the theoretical value of 2800. Urhammer and Collins (1990) have now convincingly established that the value is 2080, and we have adopted the same value in the present study. This factor leads to a reduction of all magnitudes by 0.13 units.

(7) All station corrections are found to be within ± 0.22 , and 0.10 or less for 11 of the 21 stations used. Regression comparisons with M_L values computed from the earlier used M_L scale and with M_S values available for a subset of our data have provided the necessary ties to the past.

ACKNOWLEDGMENTS

This research has been supported by British Petroleum, Conoco, Elf Aquitaine, Esso, Mobil, Norsk Hydro, Norske Shell, Phillips Petroleum, Saga Petroleum and Statoil under Contracts No. C.87168 (monitored by Norske Shell) and T.13017 (monitored by Statoil), and by the Advanced Research Projects Agency of the US Department of Defence, monitored by the Air Force Office of Scientific Research under Contract No. F49620-89-C-0038. This work was completed while one of the authors (HB), supported by a fellowship from the Royal Norwegian Council for Scientific and Industrial Research, was a visiting scientist at Science Applications International Corporation (SAIC) in San Diego, California. The authors thank Jens Havskov for providing data from the Western Norway Seismic Network, and Tormod Kværna, Gabriel Toro and Robert Uhrhammer for fruitful discussions and valuable comments.

REFERENCES

- Bakun, W.H. and W.B. Joyner (1984). The M_L scale in central California, *Bull. Seism. Soc. Am.* **74**, 1827-1843.
- Bakun, W.H. and A.G. Lindh (1977). Local magnitudes, seismic moments and coda durations for earthquakes near Oroville, California, *Bull. Seism. Soc. Am.* **67**, 615-629.
- Båth, M. (1981). Local magnitude - recent research and current trends, *Earth-Science Rev.* **17**, 315-398.
- Båth, M., O. Kulhanek, T. Van Eck and R. Wahlstrøm (1976). Engineering analysis of ground motion in Sweden, Report No 5-76, Seismological Institute, Uppsala, Sweden, 59 pp.
- Boore, D (1989). The Richter Scale: its development and use for determining earthquake source parameters, *Tectonophysics* **166**, 1-14.
- Bostock, M.G. and B.L.N. Kennett (1990). The effect of 3-D structure on L_g propagation patterns, *Geophys. J. Int.* **101**, 355-365.
- Bungum, H. (1987). Instrumentally analyzed seismicity of the Norwegian continental shelf, *ELOCS (Earthquake Loading on the Norwegian Continental Shelf) Report 2-2*, Norwegian Geotechnical Institute (Oslo), NTNf/NORSAR (Kjeller) and Principia Mechanica Ltd. (London), 82 pp.
- Bungum, H., A. Alsaker, L.B. Kvamme and R.A. Hansen (1990). Seismicity and seismotectonics of Norway and nearby continental shelf areas, *J. Geophys. Res.* (in press).
- Bungum, H. and P.B. Selnes (eds.) (1988). ELOCS: Earthquake Loading on the Norwegian Continental Shelf, *Summary Report*, Norwegian Geotechnical Institute (Oslo), NTNf/NORSAR (Kjeller) and Principia Mechanica Ltd. (London), 38 pp.
- Campbell, K.W. (1989). The dependence of peak horizontal acceleration on magnitude, distance, and site effects for small-magnitude earthquakes in California and Eastern North America, *Bull. Seism. Soc. Am.* **79**, 1311-1346.
- Dahle, A., H. Bungum and L.B. Kvamme (1990). Attenuation models inferred from intraplate earthquake recordings, *J. Earth. Eng. Structural Dynamics* (in press).
- Hansen, R.A., H. Bungum, and A. Alsaker (1989). Three recent larger earthquakes offshore Norway, *Terra Nova* **1**, 284-295.
- Havskov, J., H. Bungum, and L.B. Kvamme (1990). The Norwegian regional seismic

network and data center operation, *Phys. Earth Planet. Int.* (in press).

Hutton, L.K. and D.M. Boore (1987). The M_L scale in southern California, *Bull. Seism. Soc. Am.* **77**, 2074-2094.

Joyner, W.B. and D.M. Boore (1981). Peak horizontal acceleration and velocity from strong-motion records including records from the 1979 Imperial Valley, California, earthquake, *Bull. Seism. Soc. Am.* **71**, 2011-2038.

Kennett, B.L.N., S. Gregersen, S. Mykkeltveit and R. Newmark (1985). Mapping of crustal heterogeneity in the North Sea basin via the propagation of L_g -waves, *Geophys. J.R. astr. Soc.* **83**, 299-306.

Kvamme, L.B. and J. Havskov (1989). Q in Southern Norway, *Bull. Seism. Soc. Am.* **7**, 1575-1588.

Luco, J. E. (1982). A Note on near-source estimates of local magnitude, *Bull. Seism. Soc. Am.* **72**, 941-958.

Muir Wood, R. and G. Woo, (1987). The historical seismicity of the Norwegian continental shelf, *ELOCS (Earthquake Loading on the Norwegian Continental Shelf) Report 2-1*, Norwegian Geotechnical Institute (Oslo), NTNF/NORSAR (Kjeller) and Principia Mechanica Ltd. (London), 124 pp.

Regan, J. and D.G. Harkrider (1989). Numerical modelling of SH Lg waves in and near continental margins, *Geophys. J. Int.* **98**, 107-130.

Richter, C.F. (1935). An instrumental earthquake magnitude scale, *Bull. Seism. Soc. Am.* **25**, 1-32.

Richter, C.F. (1958). *Elementary Seismology*, W.H. Freeman and Co., San Francisco, California, 758 pp.

Urhammer, R.A. and E.R. Collins (1990). Synthesis of Wood-Anderson Seismograms from Broadband Digital Records, *Bull. Seism. Soc. Am.* (in press).

TABLE CAPTIONS

Table 1. Stations used in the M_L analysis, with code, location, number of earthquake recordings, and individual station corrections with standard deviations. Station 1 and 2 are subelements of the teleseismic NORSAR array (1970-present), 3 and 4 are the NORESS (1984-present) and the ARCESS (1988-present) regional arrays, 5-10 are from the Southern Norway Seismic Network SNSN (1979-1983), 11-15 are from the Western Norway Seismic Network WNSN (1985-present), and 16-21 are from the Northern Norway Seismic Network SEISNOR (1987-present) (Havskov *et al.*, 1990).

Table 2. Values for coefficients a and b obtained for different data sets. The last column gives the number of records (effectively contributing) in the data set. The fixed a -value was set to 1.00 for all subsets analyzed.

Table 3. Origin time, latitude, longitude, M_L magnitudes and number of records used in the estimation, for events with new M_L values greater than 3.5.

Table 4. Events used in the M_S versus M_L comparison (Figure 9).

FIGURE CAPTIONS

Figure 1. Seismic stations (left), and epicenters of events and raypaths between events and stations (right) used in the M_L analysis.

Figure 2. Magnitude - distance distribution of events used in the M_L analysis.

Figure 3. Plot of the ratio of the horizontal to vertical amplitude using data from 3 component stations NAO, NRA0, ARA0 and LOF.

Figure 4. Regional L_g wave attenuation values ($-\log A_0$) vs. epicentral distance as developed in this study for focal depths of 0 and 20 km (fully drawn lines) as compared to corresponding southern California values from Hutton and Boore (1987) (dashed lines). The inserted figure shows a blowup for the nearest 120 km.

Figure 5. Synthesized Wood-Anderson amplitudes vs. amplitudes measured on raw (observed) seismograms corrected for system response. The fully drawn line reflects a maximum-likelihood regression assuming similar errors along the two axes. Dotted lines are the two least squares regressions.

Figure 6. Regional L_g wave attenuation ($-\log A_0$) curves obtained in this study (solid line) as compared to the southern California values of Hutton and Boore (1987) (dotted line). The data points reflect the scatter in the synthesized Wood-Anderson amplitudes.

Figure 7. Residual magnitude distributions versus epicentral distance (left) and regressed magnitude (right). Dotted lines are plus and minus one standard deviation.

Figure 8. New M_L values vs. M_L obtained using the Båth *et al.* (1976) relation.

Figure 9. New M_L values vs. M_S for a subset of events. The solid line reflects a maximum-likelihood regression assuming similar errors along the two axes and the dotted lines are the two least squares regressions. See main text for details.

No	Station	Code	Lat	Lon	No	Correction
1	NORSAR	NAO	60.84	10.89	59	-0.15 $\pm$ 0.057
2	NORSAR	NC3	61.26	11.41	45	-0.21 $\pm$ 0.070
3	ARCESS	ARA0	69.54	25.51	46	0.11 $\pm$ 0.055
4	NORESS	NRA0	60.74	11.54	72	0.03 $\pm$ 0.045
5	Norefjell	NFJ	60.38	9.56	28	-0.18 $\pm$ 0.079
6	Seljord	SJD	59.56	8.61	27	-0.13 $\pm$ 0.079
7	Drangedal	DRA	59.10	9.10	23	-0.12 $\pm$ 0.083
8	Sørum	SRU	60.06	11.26	17	-0.07 $\pm$ 0.097
9	Sarpsborg	SPG	59.35	11.34	26	-0.01 $\pm$ 0.078
10	Evje	EVJ	58.58	7.96	14	-0.16 $\pm$ 0.096
11	Blåsjø	BLS	59.39	6.83	24	0.15 $\pm$ 0.063
12	Odda	ODD	59.91	6.63	34	0.00 $\pm$ 0.054
13	Høyanger	HYA	61.17	6.19	34	0.10 $\pm$ 0.053
14	Sulen	SUE	61.06	4.76	34	0.16 $\pm$ 0.053
15	Karmøy	KMY	59.21	5.25	29	0.22 $\pm$ 0.057
16	Namsos	NSS	64.53	11.97	37	0.00 $\pm$ 0.053
17	Mo i Rana	MOR	66.24	14.77	24	-0.02 $\pm$ 0.061
18	Tromsø	TRO	69.63	18.93	48	0.08 $\pm$ 0.053
19	Molde	MOL	62.57	7.55	31	0.07 $\pm$ 0.056
20	Lofoten	LOF	68.13	13.52	41	0.10 $\pm$ 0.057
21	Kautokeino	KTK	69.01	23.24	48	0.02 $\pm$ 0.055

Table 1

No	Data set	a -value	b -value	b -value when $a=1.0$	No.
1	All data	1.02 ± 0.093	0.00080 ± 0.000092	0.00082 ± 0.000048	624
2	Continental paths	0.91 ± 0.107	0.00087 ± 0.000114	0.00079 ± 0.000059	442
3	Maximum 1000 km	0.89 ± 0.109	0.00191 ± 0.000136	0.00089 ± 0.000065	576
4	N 63° all stat.	0.84 ± 0.160	0.00102 ± 0.000150	0.00089 ± 0.000070	322
5	S 63° all stat.	0.86 ± 0.160	0.00111 ± 0.000290	0.00089 ± 0.000150	302
6	N 63° north stat.	0.76 ± 0.210	0.00122 ± 0.000240	0.00098 ± 0.000110	182
7	S 63° south stat.	0.73 ± 0.160	0.00142 ± 0.000320	0.00097 ± 0.000160	282
8	$\beta_{Lg} \leq 3.8$ km/s	1.07 ± 0.100	0.00074 ± 0.000110	0.00080 ± 0.000060	456

Table 2

Origin time				Latitude	Longitude	Mag	No
1972	OCT	25	182550.5	70.900N	6.700W	4.10	2
1974	APR	28	125254.0	68.700N	16.200E	3.90	1
1975	JAN	20	104729.1	71.704N	14.205E	3.81	2
1977	APR	06	193145.1	61.734N	2.283E	4.15	1
1977	APR	30	233241.9	68.107N	10.644E	3.50	2
1977	NOV	09	141442.3	63.169N	1.934E	3.76	1
1978	SEP	19	145233.9	62.338N	1.538E	3.70	1
1981	SEP	03	183941.1	69.577N	13.964E	4.04	7
1982	APR	19	094928.0	61.650N	4.325E	3.63	5
1982	JUL	29	001657.8	61.142N	0.809E	4.12	1
1983	MAR	08	184355.7	59.647N	5.387E	4.13	5
1986	FEB	05	175335.3	62.736N	4.668E	4.72	1
1986	APR	04	224235.3	70.889N	8.873E	3.82	1
1986	JUL	14	135037.9	58.457N	13.753E	4.14	4
1986	SEP	01	221125.3	60.803N	2.929E	3.99	2
1986	OCT	26	113444.3	61.626N	3.918E	4.36	2
1987	OCT	31	100914.9	61.105N	4.294E	3.57	5
1988	JAN	31	185142.1	68.086N	9.242E	3.68	11
1988	APR	25	200933.0	78.560N	6.105E	3.60	1
1988	AUG	08	195934.0	63.672N	2.386E	4.96	5
1988	DEC	06	162141.8	77.010N	26.140E	3.74	6
1989	JAN	20	093346.2	57.618N	8.479E	4.01	5
1989	JAN	23	140628.5	61.952N	4.404E	4.82	5
1989	JAN	29	163822.2	59.651N	6.016E	4.41	5
1989	APR	16	063443.6	67.580N	33.680E	3.83	3

Table 3

Origin time				Latitude	Longitude	Ms	MI
1974	APR	28	125254.0	68.700N	16.200E	4.3	3.9
1975	JAN	20	104729.1	71.704N	14.205E	4.2	3.8
1977	APR	06	193145.1	61.734N	2.283E	4.6	4.2
1977	APR	30	233241.9	68.107N	10.644E	3.9	3.5
1981	SEP	03	183941.1	69.577N	13.964E	4.4	4.0
1982	APR	19	094928.0	61.650N	4.325E	4.1	3.6
1982	DEC	15	064441.3	62.283N	5.368E	4.1	3.5
1986	FEB	05	175335.3	62.736N	4.668E	4.8	4.7
1988	AUG	08	195934.0	63.672N	2.386E	5.3	5.0
1989	JAN	23	140628.5	61.952N	4.404E	5.1	4.8

Table 4

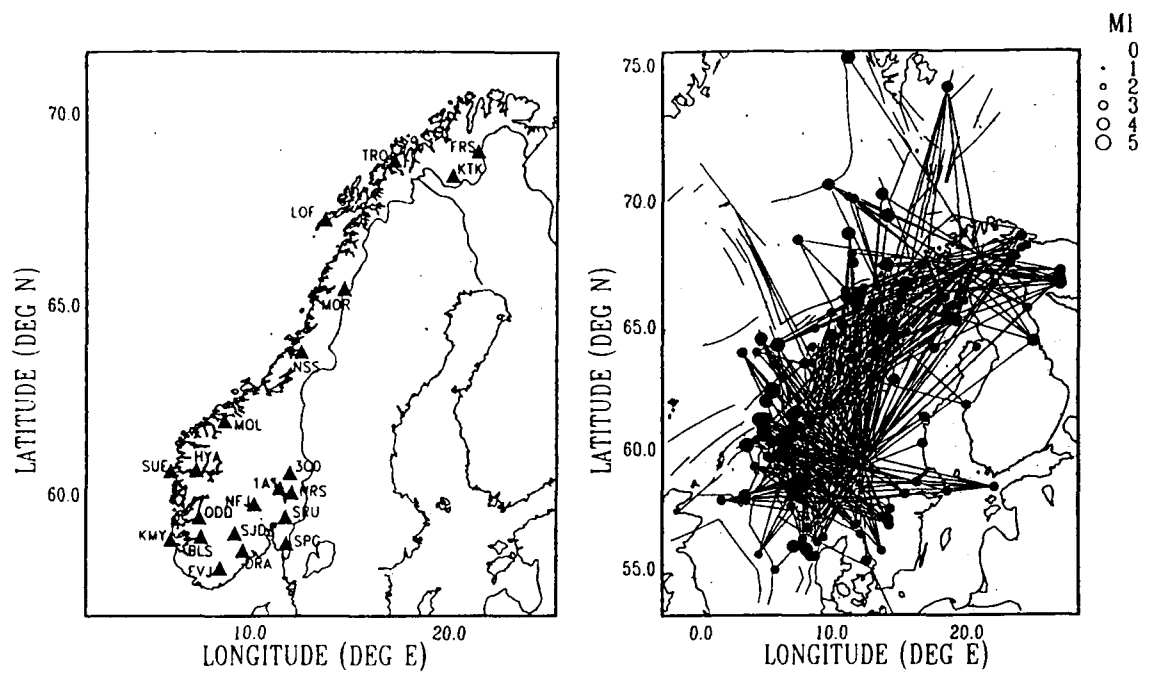


Figure 1

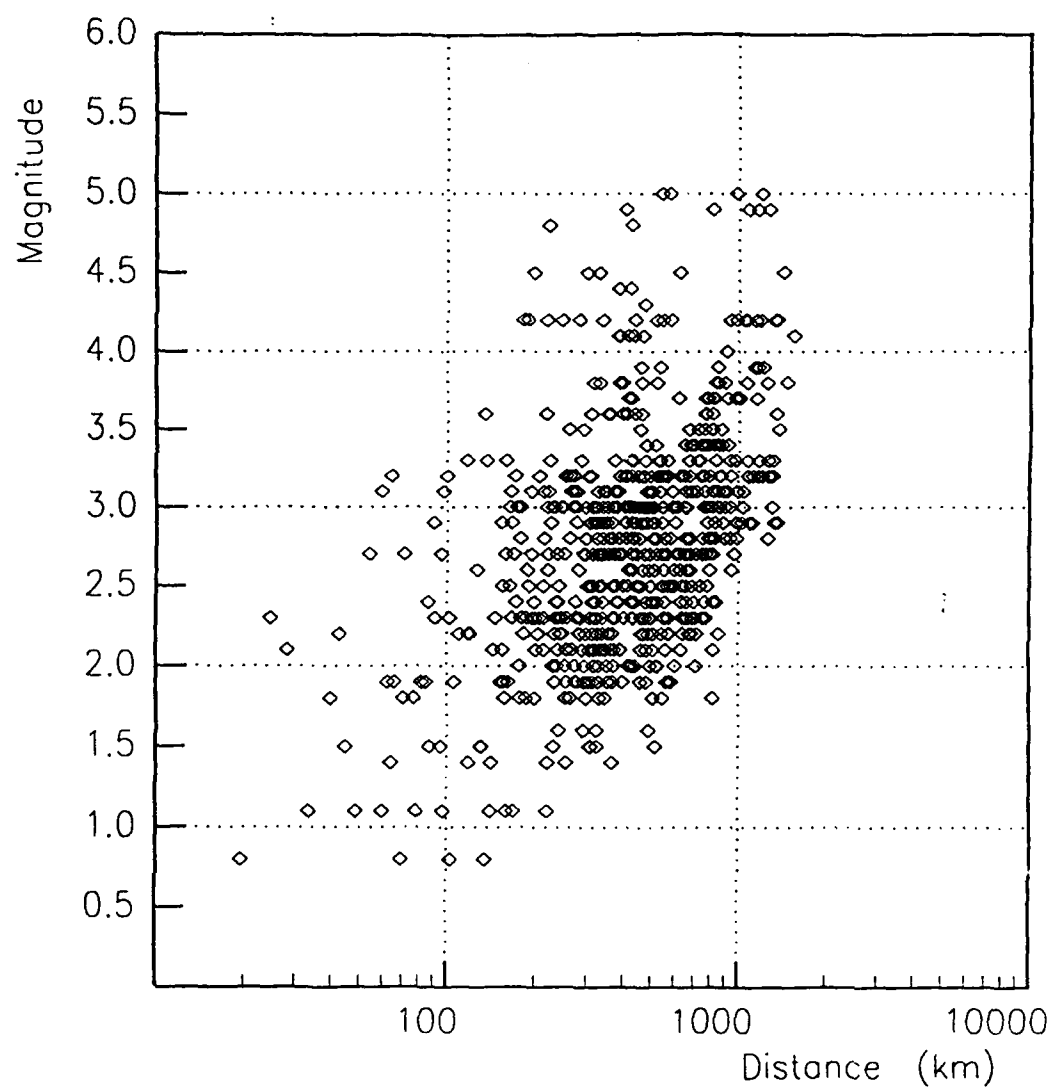


Figure 2

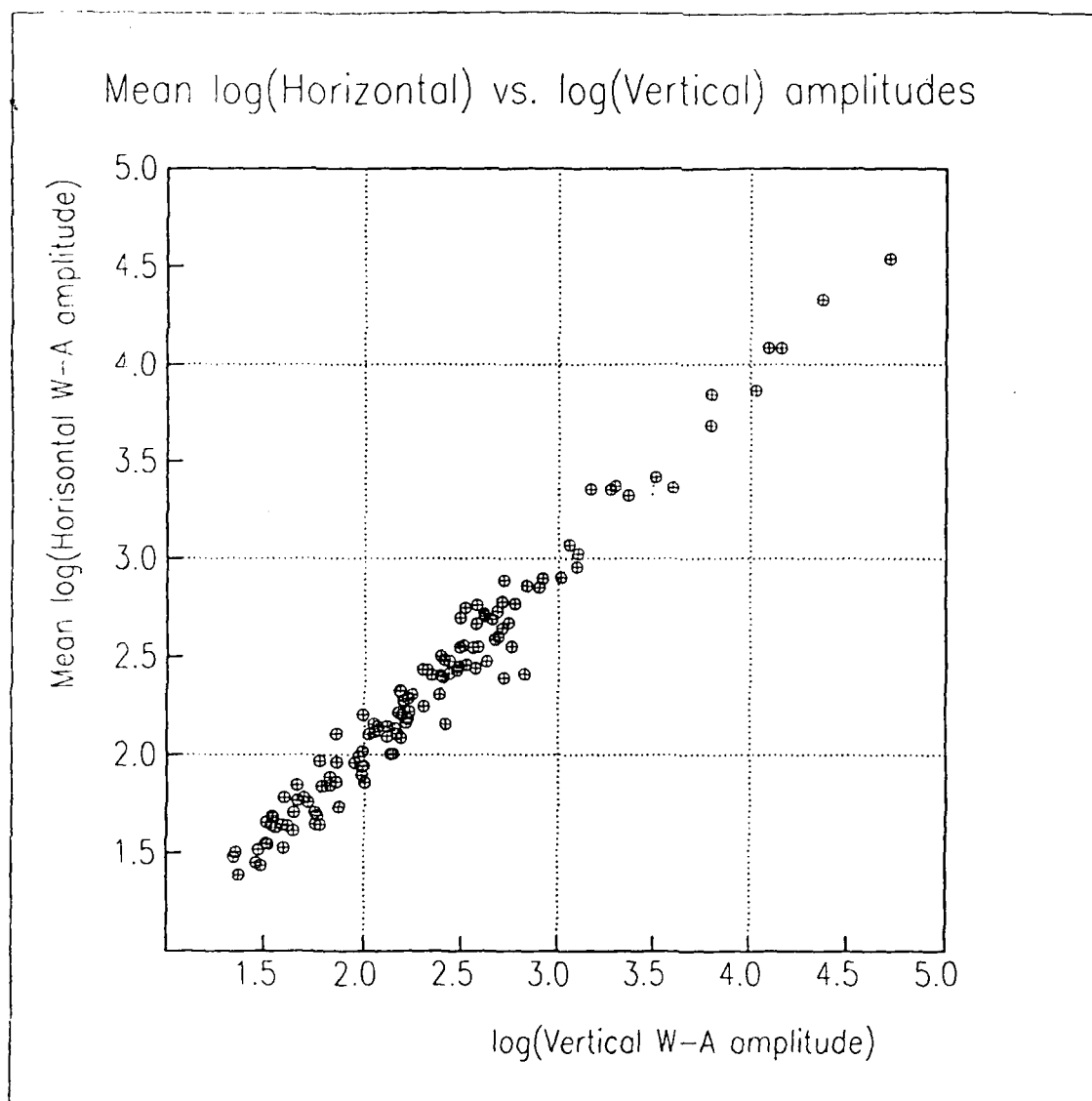


Figure 3

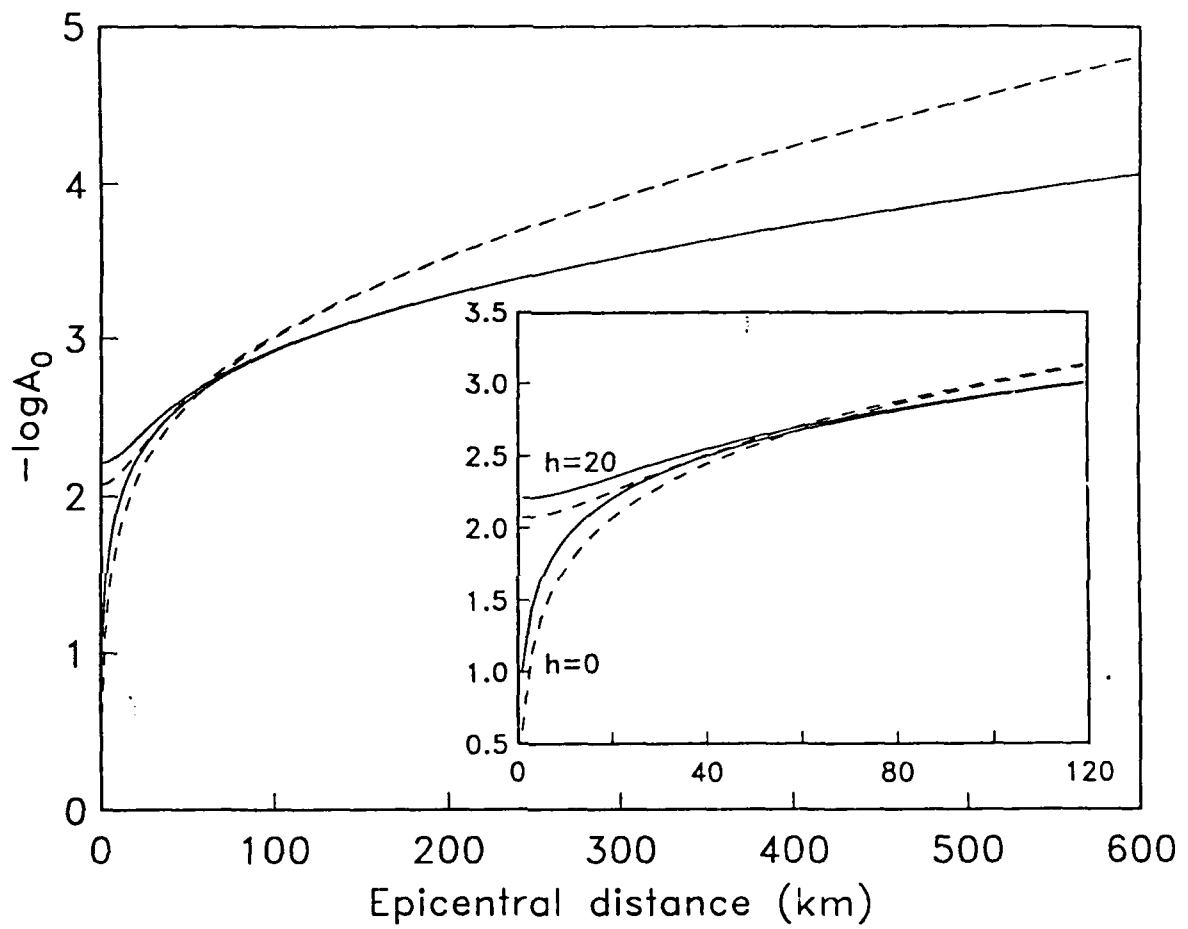


Figure 4

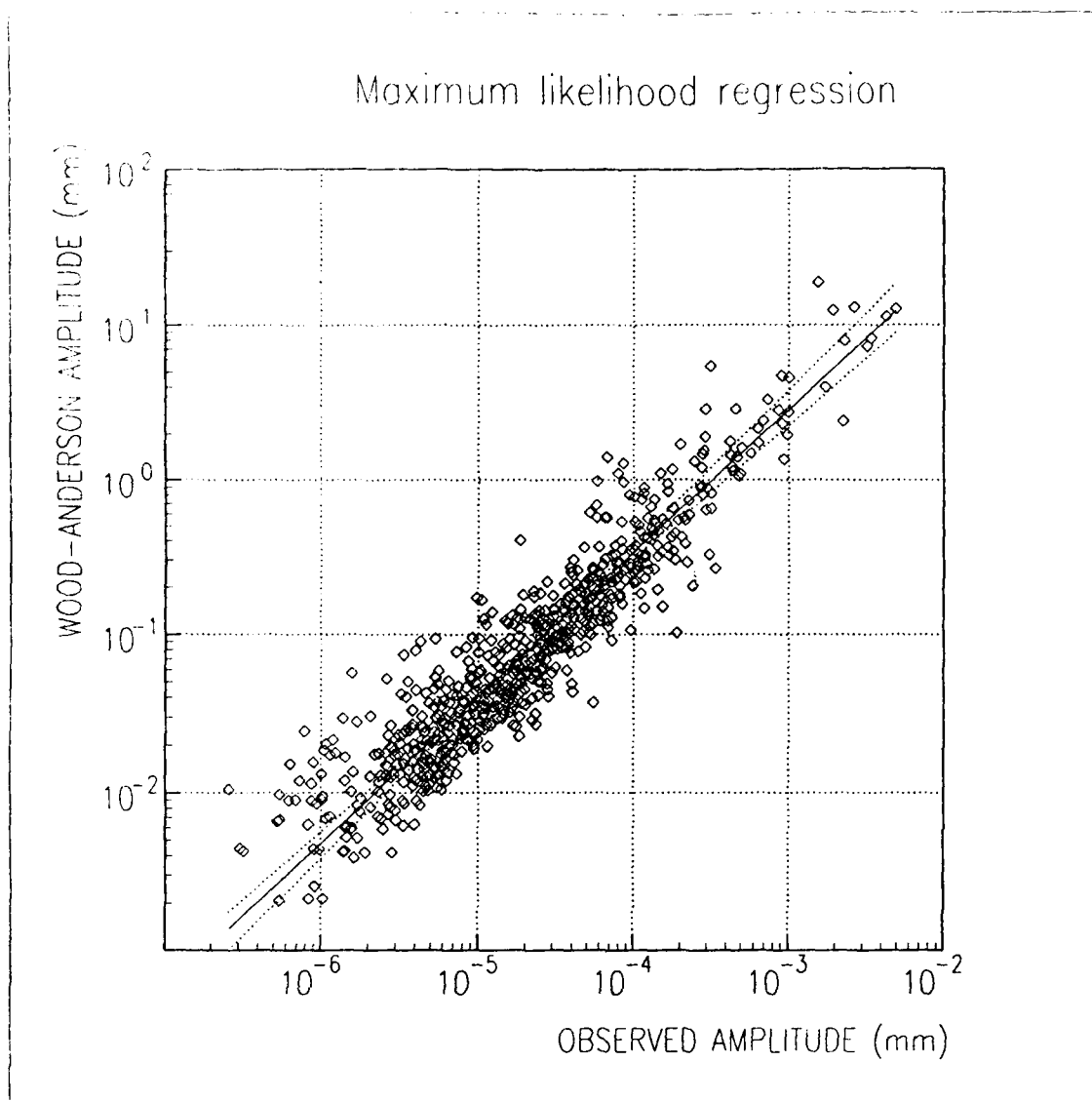


Figure 5

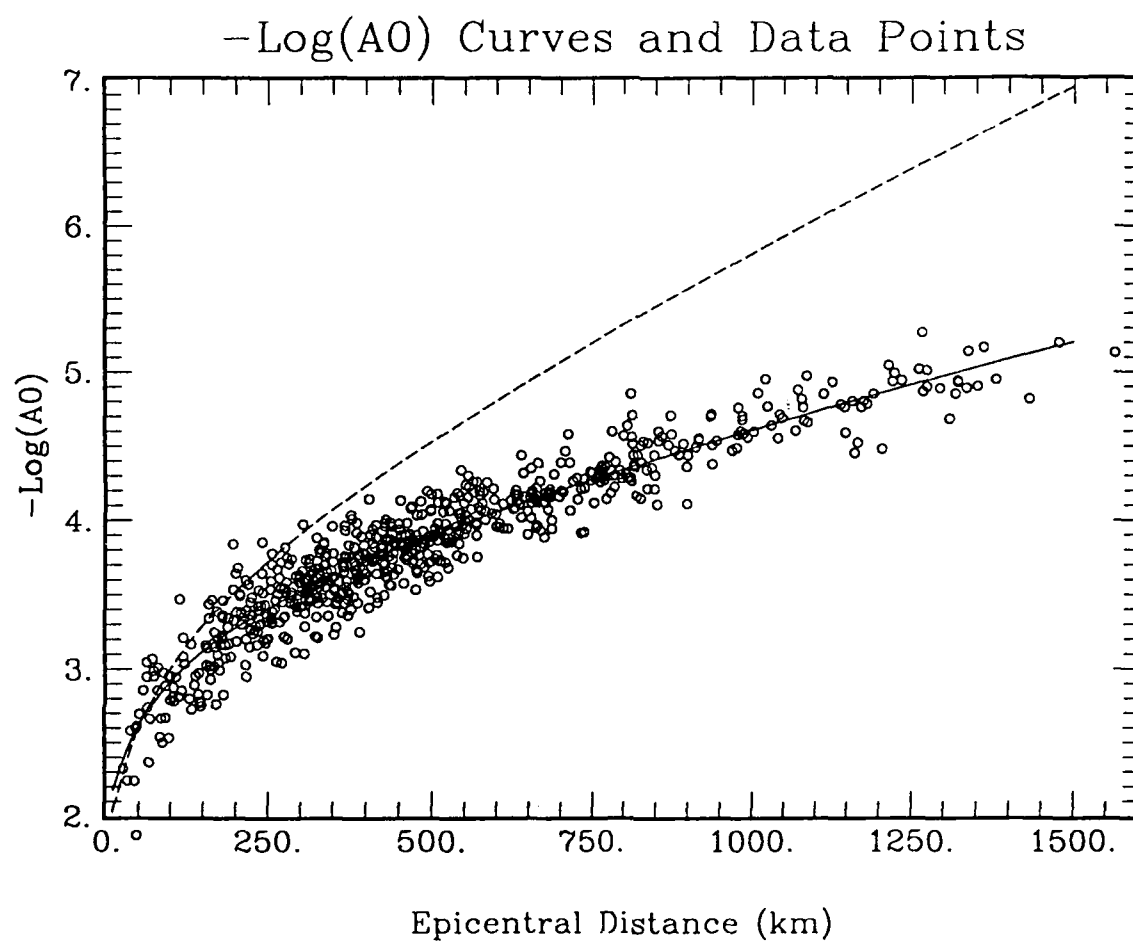


Figure 6

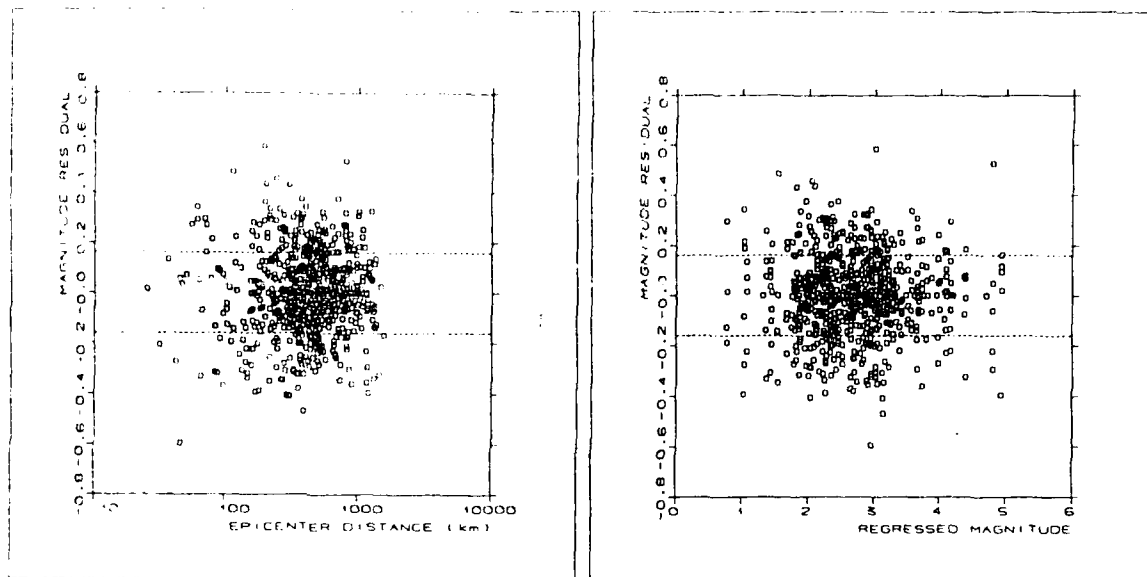


Figure 7

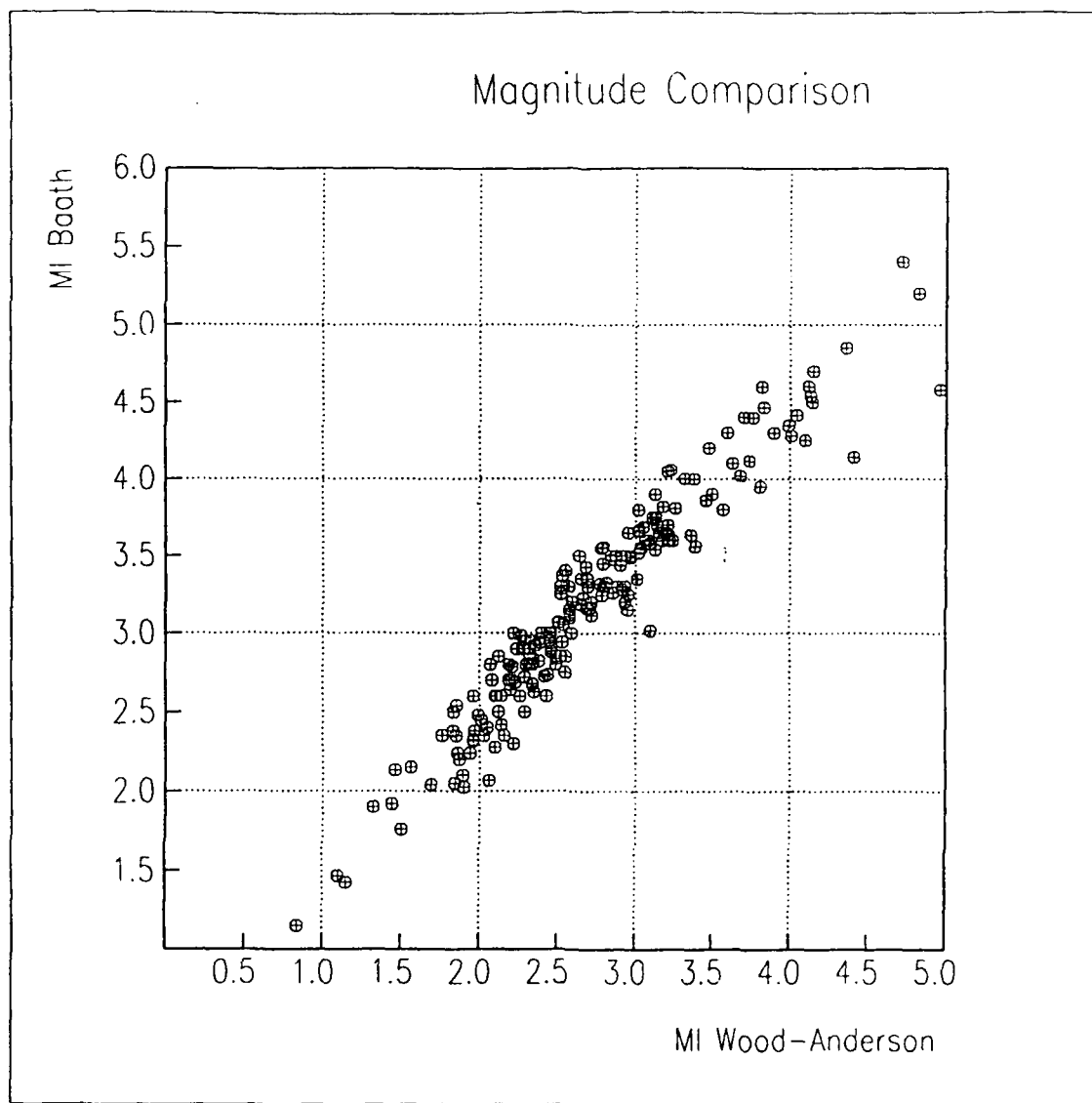


Figure 8

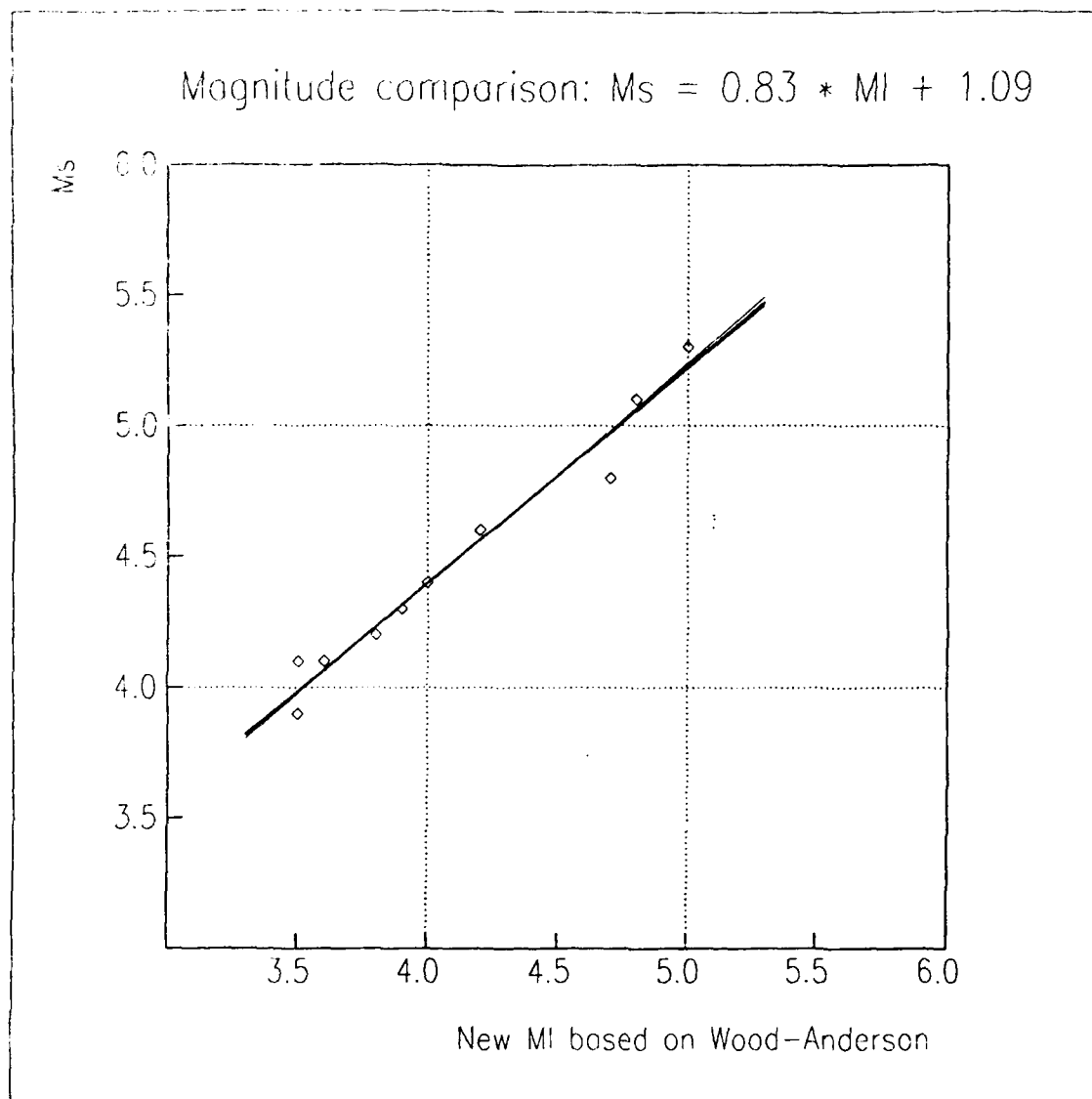


Figure 9

APPENDIX A

List of Recordings Collected and Processed

Explanation of Codes and Parameters Listed

Header line for each event

1977 APR 06 ISC 193145.1 61.734N 2.283E 10 4.4 ISC 3.9 UPP 4.6 4.2 M1W

Par no. 1:	[1977]	Year
Par no. 2:	[APR]	Month
Par no. 3:	[06]	Day of Month
Par no. 4:	[ISC]	Institution determining time and location
Par no. 5:	[193145.1]	Origin time hhmss.s of earthquake (GMT)
Par no. 6:	[61.734N]	Epicenter latitude
Par no. 7:	[2.283E]	Epicenter longitude
Par no. 8:	[10]	Focal depth in kilometers
Par no. 9:	[4.4 ISC]	Magnitude and reporting agency
Par no. 10:	[3.9 UPP]	Magnitude ML and reporting agency
Par no. 11:	[4.6]	Magnitude MS
Par no. 12:	[4.2 M1W]	NORSAR Richter compatible magnitude ML

Record line for each station

01A01 471.5 285.9 Low gain, no P-arrival (LF)

Par no. 1:	[01A01]:	Recording station code
Par no. 2:	[271.6]:	Epicenter distance in km
Par no. 3:	[285.9]:	Azimuth i degrees
Par no. 4:	[Comments..]	Comments to data or processing

Abbreviations and codes

BER	: University of Bergen, Seismological Observatory
ISC	: International Seismological Centre
NAO	: NORSAR Scientist
BKH	: Norsar Analyst
PDE	: USGS Preliminary determination of epicenters
UPP	: University of Uppsala
NOP	: University of Helsinki scientist
01A01	: NORSAR instrument 01A01

1971 NOV 08	ISC 232444.4 62.946W	5.069E	33 4.5 PDE	4.5	3.0 M1W
	DIST AZIM		Comments.....		
03C00	389.6 302.3		Saturated, no P-arrival (LF)		
01A01	385.0 310.0		Saturated, no P-arrival (LF)		
1972 OCT 25	ISC 182550.5 70.900W	6.700W	33 5.3 PDE	5.1	4.1 M1W
	DIST AZIM		Comments.....		
03C00	1333.9 325.7		Ok (LF)		
01A01	1361.1 328.5		Ok (LF)		
1973 FEB 13	ISC 000512.1 65.787W	18.887E	3.4 PEN 3.1 PEN		2.5 M1W
	DIST AZIM		Comments.....		
03C00	625.8 33.1		No P-arrival		
01A01	680.4 32.5		No P-arrival		
1973 JUN 24	ISC 210642.3 62.430W	2.004E	33 4.0 PEN		2.8 M1W
	DIST AZIM		Comments.....		
01A01	502.5 294.4		No P-arrival (LF)		
03C00	511.9 288.8		No P-arrival (LF)		
1974 APR 28	BER 125254.0 68.700W	16.200E	33 4.9 PDE 4.7 PEN 4.3		3.9 M1W
	DIST AZIM		Comments.....		
01A01	910.8 13.7		Saturated, no P-arrival (LF)		
1974 NOV 09	ISC 071423.9 69.635W	9.676E	33 3.8 PEN		3.2 M1W
	DIST AZIM		Comments.....		
03C00	937.0 355.9		No P-arrival (LF)		
01A01	981.8 357.2		Noise window = 3 sec (LF)		
1974 DEC 18	ISC 201215.6 67.854W	10.490E	33 4.3 ISC 4.1		3.2 M1W
	DIST AZIM		Comments.....		
03C00	736.3 357.0		Noise window < 5 sec (LF)		
01A01	781.7 358.8		Ok (LF)		
1975 JAN 20	ISC 104729.1 71.704W	14.205E	20 5.0 ISC 4.5 PEN 4.2		3.8 M1W
	DIST AZIM		Comments.....		
03C00	1170.8 4.8		Ok (LF)		
01A01	1219.7 5.5		Ok (LF)		
1975 NOV 12	ISC 000616.0 57.011W	7.173E	95 4.7 IGS 3.7 IGS		3.1 M1W
	DIST AZIM		Comments.....		
01A01	477.4 208.2		Saturated (LF)		
03C00	531.9 209.0		Ok (LF)		
1976 MAR 27	ISC 032447.5 56.734W	7.491E	3.5 MAO 2.4 UPP		2.3 M1W
	DIST AZIM		Comments.....		
01A01	498.0 204.7		No P-arrival		
03C00	552.3 205.8		No P-arrival		
1976 DEC 17	ISC 070950.1 62.935W	17.356E	3.6 MAC 2.9 UPP		2.7 M1W
	DIST AZIM		Comments.....		
03C00	356.6 58.0		Saturated (LF)		
01A01	406.3 54.1		Ok (LF)		
1976 APR 25	ISC 110631.7 59.544W	15.254E	3.3 PEN 2.9 PAV		2.1 M1W
	DIST AZIM		Comments.....		
01A01	281.6 118.8		Ok (LF)		
03C00	284.5 130.3		Ok (LF)		
1977 APR 06	ISC 193145.1 61.734W	2.283E	10 4.4 ISC 3.9 UPP 4.6		4.2 M1W
	DIST AZIM		Comments.....		
03C00	479.5 285.0		Low gain, no P-arrival (LF)		
03C00	488.3 280.2		Clipped		
1977 APR 14	ISC 002736.9 57.096W	6.108E	33 4.4 PDE 1.8 IGS		2.2 M1W
	DIST AZIM		Comments.....		
01A01	499.6 215.4		No P-arrival		
03C00	500.0 215.5		No P-arrival		

1977 APR 30	ISC 233241.9	68.107N	10.644E	14 4.1	ISC	3.9	3.5 M1W
	DIST	AZIM			Comments.....		
03C00	764.1	357.6			No P-arrival (LF)		
01A01	809.8	359.3			No P-arrival (LF)		
1977 NOV 07	ISC 003428.9	68.916N	28.987E	7 3.8	PEW 3.5 UPP		3.2 M1W
	DIST	AZIM			Comments.....		
03C00	1179.7	36.3			Ok		
1977 NOV 09	ISC 141442.3	63.169N	1.934E	10 4.6	PDE 4.7 IGS		3.8 M1W
	DIST	AZIM			Comments.....		
01A01	535.2	302.8			Low gain (LF)		
1977 DEC 05	ISC 034450.9	62.398N	2.172E	30 4.2	PDE 4.4 IGS		2.9 M1W
	DIST	AZIM			Comments.....		
01A01	493.2	294.3			Ok (LF)		
03C00	502.7	288.6			Ok (LF)		
1978 JAN 09	WOP 024734.6	59.860N	5.360E	3.1	MAC 2.5 WOP		2.2 M1W
	DIST	AZIM			Comments.....		
01A01	324.1	252.6			Ok		
03C00	366.8	247.5			Ok		
1978 FEB 24	ISC 110435.2	62.229N	1.806E	10 4.2	IGS 2.7 WOP		2.7 M1W
	DIST	AZIM			Comments.....		
01A01	506.6	291.7			Ok (LF)		
03C00	518.5	286.2			Ok (LF)		
1978 MAR 07	ISC 023155.2	56.764N	7.931E	33 3.0	PEW 3.5 IGS		2.1 M1W
	DIST	AZIM			Comments.....		
01A01	485.4	201.9			Ok		
03C00	539.3	203.3			Ok		
1978 MAR 16	ISC 101111.8	59.015N	1.420E	33 3.7	IGS 3.6 IGS		2.5 M1W
	DIST	AZIM			Comments.....		
01A01	566.6	253.1			Ok		
03C00	608.4	250.1			Ok		
1978 MAR 20	ISC 035739.0	62.648N	6.408E	4.3	MAC 3.2 UPP 4.1		3.1 M1W
	DIST	AZIM			Comments.....		
03C00	304.7	302.7			Clipped		
01A01	310.4	312.3			Low gain (LF)		
1978 APR 25	ISC 010236.4	58.829N	5.562E	3.0	PEW		3.1 M1W
	DIST	AZIM			Comments.....		
01A01	373.4	235.4			Low gain (LF)		
03C00	423.8	232.8			Saturated (LF)		
1978 APR 29	ISC 211101.9	64.538N	14.554E	10 3.7	MAC 3.1 UPP 3.8		2.3 M1W
	DIST	AZIM			Comments.....		
03C00	398.5	22.2			Ok (LF)		
01A01	452.4	22.9			Ok (LF) (3C)		
1978 SEP 19	ISC 145233.9	62.338N	1.538E	10 4.7	IGS		3.7 M1W
	DIST	AZIM			Comments.....		
01A01	523.0	292.6			Low gain (LF)		
1978 NOV 14	ISC 234018.3	66.919N	14.672E	3.0	WAO 3.3 UPP		2.5 M1W
	DIST	AZIM			Comments.....		
03C00	650.2	12.7			Ok		
1978 DEC 04	ISC 104626.8	66.797N	13.755E	7 3.1	WAO 3.3 UPP		2.5 M1W
	DIST	AZIM			Comments.....		
03C00	627.5	9.5			Ok		
01A01	678.3	10.7			Ok		
1978 DEC 09	IGS 210156.1	61.480N	3.200E	3.9	IGS		1.8 M1W

	DIST	AZIM		Comments.....	
01A01	419.6	283.1		Ok	
03C00	439.7	276.8		Ok	
1978 DEC 27 ISC 153334 5 66.785N 13.525E 7 2.9 NAO 3.1 UPP 2.5 M1W					
	DIST	AZIM		Comments.....	
03C00	624.2	8.6		Ok	
01A01	674.8	9.9		Ok	
1979 DEC 14 ISC 031338 7 65.058N 5.257E 10 3.6 UPP 3.0 M1W					
	DIST	AZIM		Comments.....	
03C00	524.3	326.5		Saturated (LF)	
01A01	549.3	331.2		Ok (LF) (3C)	
1979 DEC 23 ISC 140910.3 59.544N 18.834E 3.2 UPP 2.8 M1W					
	DIST	AZIM		Comments.....	
01A01	463.7	104.7		Ok (LF) (3C)	
1980 MAY 27 BRH 165556.5 67.750N 15.105E 3.0 PEN 3.6 NAO 3.0 M1W					
	DIST	AZIM		Comments.....	
03C00	744.5	12.1		Ok (Two file-sets) (LF)	
01A01	796.1	13.0		Ok (LF) (3C)	
1980 OCT 17 EKH 185730.3 62.341N 4.767E 2.9 NAO 2.9 NAO 2.2 M1W					
	DIST	AZIM		Comments.....	
HFJ	336.9	312.5		Ok	
01A01	365.1	299.8		Ok (3C)	
03C00	370.4	291.8		Ok	
SJD	373.7	327.8		Ok	
DRA	431.0	328.6		Ok	
SRU	431.2	308.8		Ok	
SPG	488.0	315.8		Ok	
1980 NOV 17 BRH 181150.0 61.796N 1.929E 2 3.0 SHH 2.4 M1W					
	DIST	AZIM		Comments.....	
HFJ	440.7	294.3		Ok	
SJD	442.2	307.2		Ok	
DRA	495.2	310.3		Ok	
SRU	540.9	294.9		Ok	
SPG	582.6	301.9		Ok	
1981 JAN 28 BRH 144322.3 65.864N 12.913E 2.9 SHH 2.4 M1W					
	DIST	AZIM		Comments.....	
HFJ	624.2	14.0		Ok	
SRU	652.0	6.7		Ok	
SPG	730.1	5.7		Ok	
SJD	736.3	15.5		Ok	
DRA	778.4	13.0		Ok, local expl. in Lg window	
1981 FEB 12 BRH 063909 2 58.913E 17.974E 3.3 UPP 2.6 M1W					
	DIST	AZIM		Comments.....	
HFJ	297.6	21.4		Saturated	
SJD	314.2	100.9		Saturated	
1981 FEB 20 BRH 113518 6 70.914N 9.068E 3.7 NAO 3.1 M1W					
	DIST	AZIM		Comments.....	
03C00	1081.3	355.5		Ok	
01A01	1125.7	356.6		Ok	
HFJ	1174.9	359.2		Ok	
SRU	1212.1	360.2		Ok	
SJD	1250.1	358.3		Ok	
DRA	1316.8	360.0		Ok	
1981 MAR 15 BRH 044636 8 61.878N 4.992E 3.0 UPP 3.1 NAO 2.6 M1W					
	DIST	AZIM		Comments.....	
HFJ	297.4	306.1		Saturated	
SJD	314.2	314.2		Saturated	

01A01	335.6	292.6			0k (3C)
DRA	382.6	325.6			0k
SRU	394.8	303.5			0k
SPG	446.8	311.7			0k
1981 MAR 20	BKH	051101.6	68.378N	8.998E	3.2 WAO 2.6 MLW
	DIST	AZIM			Comments.....
03C00	801.5	352.9			0k
WFJ	892.2	358.5			0k
SJD	983.7	0.9			0k
1981 APR 29	BKH	030849.8	61.256N	4.119E	2.9 SWH 2.4 MLW
	DIST	AZIM			Comments.....
WFJ	311.8	290.6			0k
SJD	311.8	309.3			0k
DRA	365.6	313.1			0k
SRU	412.1	291.9			0k
SPG	451.7	301.1			0k
1981 MAY 22	BKH	034230.7	55.590N	23.290E	2.9 SWH 2.3 MLW
	DIST	AZIM			Comments.....
03C00	762.4	45.7			0k
01A01	815.5	44.3			0k
1981 JUN 22	BKH	043814.6	65.794N	0.194E 9 4.3	ISC 4.0 WAO 3.2 MLW
	DIST	AZIM			Comments.....
03C00	751.0	317.1			0k (LF)
WFJ	765.4	326.0			0k
01A01	767.3	320.5			0k (LF) (3C)
SJD	816.7	331.9			0k
SRU	848.4	323.5			0k
DRA	874.1	332.2			0k
SPG	915.8	326.3			0k
1981 JUN 22	BKH	185318.6	59.469N	22.854E 19	3.2 WAO 2.7 MLW
	DIST	AZIM			Comments.....
SPG	653.3	83.9			0k
SRU	654.2	90.8			0k
03C00	661.2	102.5			0k
01A01	681.1	97.7			0k (3C)
WFJ	749.1	92.0			0k
DRA	783.8	81.1			0k
SJD	804.8	84.5			0k
1981 JUL 15	BKH	081017.0	65.663N	0.215E 29	3.3 IGS 2.2 MLW
	DIST	AZIM			Comments.....
WFJ	754.0	325.3			0k
1981 SEP 03	BKH	183941.1	69.577N	13.964E	4.8 ISC 4.7 UPP 4.4 4.0 MLW
	DIST	AZIM			Comments.....
03C00	934.5	6.1			Saturated(two file-sets)(LF)
01A01	984.0	7.0			Saturated (LF)
WFJ	1045.7	9.5			Saturated
SRU	1068.3	5.7			Saturated
SJD	1145.2	10.5			Saturated
SPG	1146.6	5.1			Saturated
DRA	1190.1	9.2			Saturated
1981 SEP 07	BKH	075207.5	72.651N	13.400E	4.3 ISC 3.5 WAO 3.2 MLW
	DIST	AZIM			Comments.....
03C00	1273.0	3.0			0k
01A01	1321.1	3.7			0k
1981 NOV 11	BKH	024852.3	57.099N	13.247E	2.7 UPP 2.9 WAO 2.3 MLW
	DIST	AZIM			Comments.....
SPG	274.9	155.1			0k
SJD	385.3	133.2			0k
WFJ	423.0	148.1			0k

01A01 438.7 161.0
03C00 475.4 166.5

Ok
Ok

1982 JAN 04 BKH 182204 2 59.279W 5.601E
DIST AZIM
SPG 326.8 271.0
01A01 342.0 241.7
03C00 390.1 238.1

2.8 NAO 3.8 2.5 MLW
Comments.....
Ok
Ok (LF) (3C)
Ok (LF)

1982 JAN 21 BKH 125739 1 68.245W 10.914E
DIST AZIM
03C00 778.9 358.5
01A01 825.1 0.1
WFJ 879.3 3.7
SJD 975.0 5.6
SPG 991.5 359.0
DRA 1022.9 4.2
EVJ 1086.8 6.5

3.2 NAO 2.8 MLW
Comments.....
Ok
Ok
Ok
Ok
Ok
Ok

1982 MAR 17 ISC 223309.7 62.089W 1.974E 10
DIST AZIM
WFJ 449.5 298.4
SJD 458.1 310.9
EVJ 511.4 322.3
DRA 512.3 313.5
SRU 549.0 298.3
SPG 594.4 304.8

4.2 IGS 2.9 MLW
Comments.....
Ok
Saturated
Ok
Ok
Ok
Ok

1982 MAR 19 BKH 005205.1 65.020W 1.422W 1
DIST AZIM
WFJ 663.2 324.7
SJD 713.3 331.6
SRU 747.7 321.8
DRA 770.7 332.0
EVJ 795.0 337.2
SPG 814.0 325.0

3.6 SHH 2.5 MLW
Comments.....
Ok
Ok
Ok
Ok
Ok, spikes in Lg window
Ok

1982 APR 19 BKH 094928.0 61.650W 4.325E
DIST AZIM
WFJ 316.5 298.8
SJD 331.0 316.7
DRA 386.8 319.2
EVJ 396.9 331.0
SPG 462.3 306.6

4.0 NAO 4.1 3.6 MLW
Comments.....
Low gain
Low gain
Low gain
Low gain
Low gain

1982 APR 20 BKH 131929.8 59.197W 6.303E
DIST AZIM
EVJ 117.5 306.3
SJD 127.3 254.1
DRA 150.1 254.9
SPG 225.1 235.1
SPG 287.6 268.7

3.6 NAO 3.2 MLW
Comments.....
Low gain
Low gain
Low gain
Low gain
Low gain

1982 APR 20 BKH 201657.8 61.140W 0.809E 20 4.4 BER 4.3
DIST AZIM
WFJ 545.1 277.1

4.1 MLW
Comments.....
Low gain (LF)

1982 AUG 06 BKH 074123.1 60.621W 6.336E
DIST AZIM
SJD 173.3 324.1
DRA 179.3 230.1
DRA 229.1 318.7
EVJ 244.9 338.7
SPG 251.1 251.1

3.3 NAO 2.9 MLW
Comments.....
Low gain
Low gain
Low gain
Low gain
Ok, some samples edited

1982 SEP 17 BKH 112612.7 60.004W 15.617E 27
DIST AZIM
WFJ 398.5 16.4

3.4 NAO 3.0 MLW
Comments.....
No visible 2nd peak

SPG	986.8	10.5			No visible P-arrival
SJD	1001.6	17.0			No visible P-arrival
DRA	1042.3	15.2			No visible P-arrival
1982 NOV 23 BKH 165836.5 60.789W 3.004E 18					3.0 NAO 2.0 MLW
	DIST	AZIM			Comments.....
SJD	340.2	296.2			Ok
WFJ	362.2	280.1			Ok
EVJ	371.8	313.5			Ok
DRA	388.7	301.5			Ok
SRU	461.4	283.7			Ok
1982 DEC 09 BKH 202108.0 66.375W 7.790E 4.4					ISC 3.2 NAO 3.4 MLW
	DIST	AZIM			Comments.....
WFJ	674.2	353.2			Ok
SRU	724.6	347.6			Ok
SJD	761.2	357.2			Ok
SPG	803.0	348.6			Ok
DRA	813.1	355.9			Ok
EVJ	868.5	359.5			Ok
1982 DEC 15 BKH 064441.3 62.283W 5.368E					3.8 NAO 4.1 3.5 MLW
	DIST	AZIM			Comments.....
WFJ	308.8	315.2			Low gain
SJD	351.1	331.3			Low gain
DRA	408.5	331.7			Low gain
EVJ	436.2	342.0			Low gain
SPG	460.3	317.7			Low gain
1982 DEC 27 BKH 181516.4 61.620W 3.837E 3					3.0 NAO 2.8 MLW
	DIST	AZIM			Comments.....
WFJ	339.1	296.5			Low gain
SJD	348.3	313.4			Low gain
DRA	403.3	316.3			Low gain
EVJ	408.7	327.6			Ok
SRU	438.9	296.5			Ok
SPG	483.2	304.7			Ok
1983 JAN 04 BKH 024033.6 58.568W 0.451W					3.2 NAO 2.3 MLW
	DIST	AZIM			Comments.....
EVJ	436.7	273.0			No P-arrival visible
SJD	480.8	260.3			No P-arrival visible
DRA	502.5	266.9			No P-arrival visible
WFJ	553.9	252.6			No P-arrival visible
SRU	636.7	259.6			No P-arrival visible
1983 FEB 24 BKH 041947.1 60.291W 1.869E					3.0 NAO 2.6 MLW
	DIST	AZIM			Comments.....
SJD	385.9	285.2			Ok
EVJ	394.4	301.4			Ok
WFJ	424.8	272.0			Ok
DRA	427.7	291.1			Ok
SRU	521.2	276.9			Ok
SPG	541.0	285.2			Ok
1983 MAR 08 BKH 184355.7 59.647W 5.387E 4.8					PDE 4.7 NAO 4.1 MLW
	DIST	AZIM			Comments.....
SJD	182.5	274.6			Low gain
EVJ	189.2	309.9			Low gain
DRA	219.4	287.6			Low gain
WFJ	246.6	252.5			Low gain
SPG	338.6	278.1			Low gain
1983 MAR 08 BKH 185206.1 59.713W 5.452E					3.0 NAO 2.3 MLW
	DIST	AZIM			Comments.....
EVJ	190.9	312.3			Low gain
WFJ	240.7	253.8			Low gain
SRU	327.3	265.7			Ok

SPG	335.4	279.4				0k	
1986 JAN 19	ISC 045925.2	64.673W	12.668E			3.3 WOP	2.5 MLW
	DIST	AZIM				Comments.....	
WORESS	442.7	7.0				0k (3C)	
1986 JAN 25	ISC 231323.6	61.710W	17.006E	10		3.3 UPP	2.3 MLW
	DIST	AZIM				Comments.....	
WORESS	313.0	67.3				0k (3C)	
1986 JAN 31	WOP 060016.0	65.400W	10.300E			3.0 WOP	2.3 MLW
	DIST	AZIM				Comments.....	
WORESS	523.7	353.7				0k (3C)	
1986 FEB 05	BER 175335.3	62.736W	4.668E	16	5.0 PDE 4.2 BER 4.8		4.7 MLW
	DIST	AZIM				Comments.....	
STF	222.5	40.9				0k (problems)	
WORESS	425.9	304.5				0k (BF) (IP) (3C)	
1986 APR 01	BER 095658.0	56.644W	12.014E	15	3.6 BER 3.3 BER		3.5 MLW
	DIST	AZIM				Comments.....	
WORESS	456.5	176.4				0k (C4) (IP) (3C)	
1986 APR 04	BER 224235.3	70.889W	8.873E	29	4.6 PDE 3.5 BER		3.8 MLW
	DIST	AZIM				Comments.....	
WORESS	1138.5	355.1				0k (C4) (IP) (3C)	
1986 JUN 15	BER 150105.9	61.670W	3.906E			3.0 BER	2.9 MLW
	DIST	AZIM				Comments.....	
WORESS	423.2	287.6				0k (C4) (3C)	
1986 JUL 14	UPP 111955.0	66.500W	14.500E			3.0 UPP	2.5 MLW
	DIST	AZIM				Comments.....	
WORESS	659.0	11.5				0k (C4) (3C)	
1986 JUL 14	BKH 135037.9	58.457W	13.753E	16	4.1 UPP 3.9 BER		4.1 MLW
	DIST	AZIM				Comments.....	
WORESS	282.8	152.8				0k (BF) (IP) (3C)	
ODD	438.1	108.6				Clipped	
BYA	520.4	122.1				0k	
SUE	581.9	115.9				0k	
1986 JUL 14	BKH 144531.2	58.210W	13.872E	21	3.4 WAO 3.1 BER		2.8 MLW
	DIST	AZIM				Comments.....	
WORESS	310.7	153.8				0k (C4) (3C)	
BLS 14	427.7	104.9				0k	
ODD	456.5	111.4				0k	
BYA	543.3	123.9				0k	
SUF	603.2	117.7				0k	
1986 AUG 15	BER 184 57	60.821E	13.174E	10	3.4 WAO		3.0 MLW
	DIST	AZIM				Comments.....	
WORESS	683.5	6.0				0k (C2) (3C)	
1986 AUG 04	WOP 195541.0	65.800W	5.800E			3.0 WOP	2.1 MLW
	DIST	AZIM				Comments.....	
WORESS	633.3	335.5				0k (C4) (3C)	
1986 AUG 29	BER 073819.4	50.779W	3.961E	4		2.9 BER	2.5 MLW
	DIST	AZIM				Comments.....	
WORESS	413.1	274.0				0k (C2) (3C)	
1986 SEP 01	BER 221125.3	60.803W	2.929E	12	3.5 BER 3.5 BER		4.0 MLW
	DIST	AZIM				Comments.....	
01101	432.7	272.9				Low gain (LF)	
WORESS	469.1	274.7				0k (C2) (TP) (3C)	
1986 SEP 20	BER 221125.3	60.803W	2.929E	12	3.5 BER		4.0 MLW

	DIST	AZIM			Comments.....
WORESS	273.4	104.6			Ok (C2) (3C)
BLS 14	537.0	78.3			Ok
ODD	539.3	84.4			Ok
HYA	567.2	98.4			Ok
KMY	629.1	76.9			Ok
SUE	642.1	95.2			Ok
1986 OCT 26	BER 113444.3	61.626W	3.918E	11 4.5	PDE 4.0 BER 4.4 M1W
	DIST	AZIM			Comments.....
01A01	384.1	286.1			Low gain (LF)
WORESS	421.7	286.9			Ok (C2) (IP) (3C)
1986 NOV 02	BER 074800.6	58.577W	13.420E	11 3.4	BER 3.4 BER 3.2 M1W
	DIST	AZIM			Comments.....
WORESS	262.7	155.4			Ok (C2) (3C)
BLS 14	389.6	100.6			Clipped, processed
ODD	414.2	108.7			Ok
KMY	476.2	95.0			Ok
HYA	496.9	122.3			Ok
SUE	558.3	115.8			Ok
1987 JAN 06	WOP 044444.0	65.700W	0.200E		3.5 WOP 2.6 M1W
	DIST	AZIM			Comments.....
WORESS	792.6	319.1			Ok (3C)
1987 JAN 19	BER 040732.2	55.970W	4.871E		2.9 BER 2.2 M1W
	DIST	AZIM			Comments.....
WORESS	658.3	219.2			Ok (3C)
1987 FEB 04	BER 120244.0	61.586W	4.586E	17 3.7	WB2 3.3 BER 3.1 M1W
	DIST	AZIM			Comments.....
SUE	59.7	351.0			Clipped, processed
HYA	97.6	299.4			Clipped, processed
ODD	214.7	329.0			Ok
KMY	267.0	352.4			Ok
BLS 14	273.9	334.2			Clipped, processed
WORESS	386.1	287.2			Ok (3C)
WSS	496.6	232.0			Ok
1987 MAR 01	BER 064208.1	57.285W	6.821E	10	3.2 BER 3.0 M1W
	DIST	AZIM			Comments.....
KMY	233.7	156.0			Ok
ODD	297.0	178.2			Ok
HYA	433.9	174.9			Ok
SUE	436.4	163.4			Ok
WORESS	470.1	217.3			Ok (3C)
MOL	590.2	184.3			Ok
1987 APR 04	WOR 072914.3	67.382W	7.549E	30	3.1 BER 3.0 M1W
	DIST	AZIM			Comments.....
LOF	265.9	254.5			Ok
MOR	341.8	295.2			Clipped, processed
WSS	375.9	329.7			Saturated
MOL	536.5	0.0			Ok
HYA	696.1	4.8			No P-arrival
SUE	717.8	9.6			Noise window < 1 sec
WORESS	765.8	347.0			Ok (3C)
ODD	829.6	2.6			Ok
KMY	917.8	6.2			Ok, long period pulse in Lg
1987 APR 19	WOR 123953.2	67.873W	19.624E	1 3.2	BER 3.2 BER 3.0 M1W
	DIST	AZIM			Comments.....
KTK	195.1	231.1			Ok
MOR	279.0	47.0			Clipped, processed
WSS	507.1	39.3			Ok, 1 sec datagap in Lg win.
MOL	815.1	38.3			Ok
WORESS	885.1	22.6			Ok (3C)

1987 APR 19 MOR 221525.5 57.369W 8.023E
 DIST AZIM
 KMY 262.0 140.4
 ODD 298.1 164.1
 MORESS 425.7 209.8
 HYA 435.7 165.3
 SUE 451.0 154.2
 MOL 580.1 177.2
 WSS 825.8 196.7

2.9 BER 2.8 MLW
 Comments.....
 Saturated, no P-arrival
 No P-arrival
 Ok (3C)
 Ok
 Ok
 Ok
 Ok

1987 MAY 21 HEL 163141.0 67.1 W 20.6 E 0
 DIST AZIM
 MOR 275.1 66.9
 LOF 321.9 107.6

2.1 HEL M 2.2 MLW
 Comments.....
 Ok
 Ok

1987 MAY 25 MOR 023525.6 61.783W 4.748E
 DIST AZIM
 MORESS 382.6 290.7

3.1 BER 2.7 MLW
 Comments.....
 Ok (3C)

1987 MAY 27 WOP 024801.0 67.700W 22.700E
 DIST AZIM
 MORESS 943.8 30.0

3.0 WOP 2.6 MLW
 Comments.....
 Ok

1987 JUN 14 MOR 032011.7 69.422W 14.173E 6
 DIST AZIM
 LOF 146.3 10.0
 TRO 187.1 265.0
 WSS 553.8 9.0

2.9 BER 2.3 MLW
 Comments.....
 Ok
 Ok
 Ok

1987 JUN 16 MOR 114716.8 66.434W 15.169E
 DIST AZIM
 MOR 28.3 39.2
 LOF 202.2 158.7
 WSS 258.8 33.5

3.0 BER 2.1 MLW
 Comments.....
 Clipped, processed
 Ok
 Ok

1987 SEP 04 MOR 013149.4 69.525W 13.427E 15
 DIST AZIM
 LOF 155.4 358.6
 TRO 214.6 269.4
 KTK 391.5 283.0
 WSS 560.5 5.8
 MOL 819.2 16.3

2.9 BER 2.0 MLW
 Comments.....
 Ok
 Ok
 Ok
 Ok
 Ok

1987 SEP 04 MOR 083820.4 61.363W 3.002E 15
 DIST AZIM
 STF 64.6 78.8
 SUE 100.5 290.6
 HYA 172.3 278.7
 ODD 254.8 309.7
 KMY 269.9 333.6
 MOL 273.7 242.6
 BLS 14 304.6 317.8
 0140 428.0 211.2
 03CO 450.0 275.1
 MORESS 466.3 282.2
 WSS 575.2 236.2

2.9 BER 3.2 MLW
 Comments.....
 Clipped, processed
 Clipped, processed
 Clipped, processed
 Saturated
 Saturated (Ok)
 Ok
 Saturated
 Low gain (LF)
 Ok (LF)
 Ok (3C)
 Ok

1987 SEP 05 MOR 011722.9 65.656W 12.349E 15
 DIST AZIM
 WSS 126.7 8.0
 LOF 290.9 191.1
 MOL 415.8 32.1
 WOP 550.0 3.9
 KTK 538.1 276.5

3.4 BER 2.5 MLW
 Comments.....
 Clipped, processed
 Ok
 Ok
 Ok (3C)
 Ok

1987 SEP 05 HFL 124958.6 65.19 W 0.07 E 10
 DIST AZIM

3.0 HFL 3.2 MLW
 Comments.....

MOL	468.9	311.8			0k
NSS	568.1	282.8			0k
LOF	677.5	247.4			0k
NORESS	763.1	315.5			0k (3C)
RTK	1084.5	258.0			0k
1987 SEP 08	MOR 094941.0 66.569N 14.500E		15	3.2 BER	2.3 MLW
	DIST	AZIM		Comments.....	
LOF	179.3	166.0		0k	
NSS	255.6	26.1		0k	
RTK	457.7	237.6		0k	
MOL	556.0	33.7		0k	
NORESS	666.5	11.4		0k, local event in Lg window	
1987 SEP 11	MOR 163043.5 66.895N 21.073E		15	3.2 BER	M 1.9 MLW
	DIST	AZIM		Comments.....	
RTK	252.8	202.0		0k	
TRO	318.0	162.8		0k	
LOF	350.3	109.7		0k	
NSS	493.6	53.7		0k	
1987 SEP 17	HEL 163552.0 67.1 N 20.6 E		0	2.1 HEL	M 2.1 MLW
	DIST	AZIM		Comments.....	
RTK	239.8	208.5		0k	
TRO	290.8	165.5		0k	
LOF	321.9	107.6		0k	
1987 SEP 20	MOR 063745.7 67.637N 15.042E		15	2.9 BER	1.9 MLW
	DIST	AZIM		Comments.....	
LOF	84.4	130.2		0k	
MOR	156.5	4.3		0k	
TRO	272.9	217.2		0k	
1987 OCT 04	BER 022509.9 58.793N 1.621E		16 3.4	BGS 2.6 BER	2.5 MLW
	DIST	AZIM		Comments.....	
KMY	213.5	258.9		0k	
BLS 14	305.7	259.7		0k (wrong gain)	
SUE	307.3	216.2		0k	
ODD	314.4	248.0		0k	
HYA	367.1	226.0		0k	
NORESS	597.3	253.1		0k (3C)	
1987 OCT 19	MOR 053410.6 59.747N 6.631E		6	3.0 BER	2.8 MLW
	DIST	AZIM		Comments.....	
MOL	318.4	189.3		Saturated	
1987 OCT 31	MOR 100914.9 61.105N 4.294E		19 4.2	PDE 3.3 BER	3.6 MLW
	DIST	AZIM		Comments.....	
STF	134.3	96.1		0k	
KMY	217.4	346.3		Clipped, processed	
01A01	358.0	277.5		Low gain (LF)	
NORESS	395.1	279.1		0k (3C)	
MOR	770.3	227.0		0k	
ARCESS	1351.0	236.5		0k (3C)	
1987 NOV 01	MOR 203935.6 65.076N 11.807E		10 3.3	BER 3.3 BER	3.1 MLW
	DIST	AZIM		Comments.....	
MOL	349.2	35.0		0k	
LOF	349.2	193.4		0k (3C)	
NORESS	484.1	1.5		0k (3C)	
TRO	592.5	214.4		0k	
RTK	661.7	234.0		0k	
ARCESS	768.7	236.3		0k (3C)	
1987 NOV 03	MOR 223515.3 68.324N 15.542E		10	3.0 BER	2.3 MLW
	DIST	AZIM		Comments.....	
LOF	86.3	74.7		Clipped, processed	
TRO	199.2	224.5		0k	

KTK	321.5	259.8				0k
ARCESS	421.6	256.0				0k (3C)
1987 NOV 12 WOP 055256.0 68.200N 26.600E						
	DIST	AZIM				2.9 WOP 2.4 MLW
ARCESS	155.3	163.0				Comments.....
						0k (3C)
1987 DEC 23 BKH 125932.2 69.4 N 30.8 E 0						
	DIST	AZIM				3.1 HEL M 3.1 MLW
ARCESS	207.8	91.7				Comments.....
						0k, Rg phase present (3C)
1987 DEC 26 BER 165742.2 59.788N 6.359E 3.3 BER 2.6 BER 2.9 MLW						
	DIST	AZIM				Comments.....
KMY	89.9	44.0				Saturated
HYA	153.8	176.4				0k
SUE	166.6	147.4				0k
Q1A01	276.4	246.8				Low gain (LF)
WORESS	305.6	252.1				0k (3C)
O3COO	322.4	241.6				0k (LF)
1988 JAN 03 NOR 203653.3 67.590N 10.399E 10						
	DIST	AZIM				3.1 BER 2.0 MLW
LOF	144.7	246.8				Comments.....
WSS	348.4	349.0				0k
						0k
1988 JAN 12 HEL 153304.0 67.1 N 20.6 E 0						
	DIST	AZIM				3.0 BER M 1.6 MLW
KTK	239.8	208.5				Comments.....
TR0	290.8	165.5				0k
LOF	321.9	107.6				0k
WSS	487.1	50.2				0k
1988 JAN 19 BER 070209.2 61.074N 4.306E 12						
	DIST	AZIM				2.8 BER 2.3 MLW
SUE	24.6	274.6				Comments.....
HYA	101.9	265.0				Clipped, processed
ODD	180.3	315.0				0k
KMY	213.9	346.3				0k
BLS 14	233.9	324.4				0k
1988 JAN 23 NOR 062135.7 65.653N 2.108E 10 4.9 PDE 3.1 BER 3.3 MLW						
	DIST	AZIM				Comments.....
MOL	433.8	324.8				0k
SUE	529.1	346.6				0k
HYA	539.8	339.6				0k
LOF	570.3	246.4				0k (3C)
ODD	676.5	341.9				0k
KMY	735.8	348.7				0k
TR0	836.8	246.1				0k
STK	976.3	257.6				0k
WORESS	123.8	323.2				0k
ARCESS	1077.1	257.6				0k (3C)
1988 JAN 24 NOR 111045.3 67.074N 13.447E 10 2.3 BER 3.2 BER 2.1 MLW						
	DIST	AZIM				Comments.....
LOK	110.0	328.5				Saturated
LOF	118.0	181.6				0k (3C)
KTK	461.5	246.7				0k
ARCESS	567.0	246.8				0k
MOL	574.5	26.5				0k, noisy
WORESS	712.8	6.7				0k
1988 JAN 29 NOR 125444.0 69.125N 10.385E 10 3.1 BER 3.2 BER M 2.7 MLW						
	DIST	AZIM				Comments.....
ARCESS	118.1	102.6				0k, Rg phase present (3C)
TR0	434.0	92.3				0k
LOF	672.7	73.0				0k (3C)
SS	933.6	48.9				k

WORESS 1266.1	34.8			0k	
1988 JAN 31	NOR 185142.1	68.086W	9.242E	10 4.3	PDE 3.5 BER 3.7 MLW
	DIST	AZIM			Comments.....
WSS	414.8	344.1			Clipped, processed
TRO	425.9	250.7			Clipped, processed
MOL	620.0	6.5			Ok
03COO	767.8	353.2			Ok (LF)
HYA	785.0	9.4			Ok
01A01	811.2	355.1			Low gain (LF)
SUE	812.1	13.3			Ok
WORESS	826.9	353.3			Ok (3C)
ODD	915.5	6.8			Ok
BLS 14	976.5	5.9			Ok
KMY	1008.3	9.5			Ok
1988 FEB 01	HEL 124049.4	66.44 W	14.71 E	0	3.3 BER 2.4 MLW
	DIST	AZIM			Comments.....
TRO	397.1	208.3			Ok
RTK	460.2	235.5			Ok
MOL	551.2	35.4			Ok
ARCESS	567.3	237.7			Ok (3C)
WORESS	654.9	12.5			Ok (3C)
1988 FEB 18	BER 215037.5	60.705W	3.254E	11	2.7 BER 2.3 MLW
	DIST	AZIM			Comments.....
SUE	90.8	245.1			Ok
HYA	167.1	253.4			Ok
KMY	200.2	327.1			Ok
ODD	206.5	295.5			Ok
BLS 14	247.1	307.9			Ok
1988 FEB 24	NOR 175716.1	66.431W	14.624E	10	3.2 BER 2.2 MLW
	DIST	AZIM			Comments.....
LOF	195.5	165.5			Ok
WSS	245.0	29.0			Ok
TRO	399.6	208.7			Ok
RTK	463.7	235.8			Ok
MOL	547.9	35.2			Ok
ARCESS	570.8	237.9			Ok (3C)
WORESS	653.0	12.2			Ok (3C)
1988 FEB 29	NOR 184947.9	67.295W	20.492E	10	3.0 BER M 2.2 MLW
	DIST	AZIM			Comments.....
ARCESS	323.6	221.8			Ok (3C)
WORESS	850.5	26.9			Ok, noisy
1988 MAR 02	NOR 123838.0	69.238W	29.598E	10	3.1 BER M 2.4 MLW
	DIST	AZIM			Comments.....
ARCESS	164.2	99.7			Ok, Rg phase present (3C)
1988 MAR 03	HEL 173752.4	72.56 W	13.52 E	0	3.1 BER 2.5 MLW
	DIST	AZIM			Comments.....
ARCESS	548.7	313.4			Ok (3C)
1988 MAR 05	BKH 95517.6	67.381W	34.116E	0	3.3 BER M 3.2 MLW
	DIST	AZIM			Comments.....
ARCESS	426.4	120.2			Ok (3C)
1988 MAR 06	BER 031132.0	60.007W	5.875E	1	2.0 BER 1.5 MLW
	DIST	AZIM			Comments.....
ODD	44.7	278.5			Ok
BLS 14	87.2	322.5			Ok
KMY	95.4	21.5			Ok
HYA	130.3	187.7			Ok
SUE	132.0	151.9			Ok
1988 MAR 09	BER 170715.3	60.940W	4.011E	2	2.7 BER 2.2 MLW

	DIST	AZIM		Comments.....
SUE	42.6	252.5		Ok, S energy in P window
HYA	120.2	258.9		Ok
ODD	183.1	308.2		Ok
KMY	204.5	340.9		Ok
BLS 14	232.9	319.1		Ok
1988 MAR 17	BER 185807.0	59.678W	5.516E 10	3.2 BER 2.7 M1W
	DIST	AZIM		Comments.....
KMY	54.1	16.3		Clipped, processed
ODD	71.3	245.4		Clipped, processed
SUE	159.2	164.5		Saturated
HYA	169.9	192.9		Ok
O1A01	324.4	248.7		Low gain (LF)
WORESS	354.1	253.2		No P-arrival (3C)
O3C00	369.1	244.0		Ok (LF)
1988 MAR 21	BER 201947.9	61.313W	4.431E 10	3.0 BER 2.7 M1W
	DIST	AZIM		Comments.....
HYA	95.7	280.6		Clipped, processed
ODD	195.0	322.1		Ok
KMY	238.4	349.4		Ok
BLS 14	251.8	329.3		Ok
WORESS	389.6	282.6		Ok (3C)
1988 MAR 31	BER 025607.8	56.533W	3.383E 15	2.8 BER 4 2.4 M1W
	DIST	AZIM		Comments.....
KMY	318.2	201.1		Ok
BLS 14	377.8	214.1		Ok
ODD	426.6	208.3		Ok
SUE	510.2	189.6		Ok
1988 APR 24	HEL 211251.0	67.88 W	10.15 E 15	3.6 HEL 2.8 M1W
	DIST	AZIM		Comments.....
ARCESS	647.4	260.7		Ok (3C)
WORESS	799.4	355.8		Ok (3C)
1988 APR 25	PDE 200933.0	78.560W	6.105E 10 4.8 PDE 4.4	3.6 M1W
	DIST	AZIM		Comments.....
ARCESS	1157.0	338.5		Ok (3C)
1988 MAY 03	BER 063413.3	57.313W	6.775E 15 2.0 BER 2.6 BER	2.0 M1W
	DIST	AZIM		Comments.....
KMY	229.7	156.4		Ok
BLS 14	231.4	180.8		Ok
ODD	293.8	178.7		Ok
HYA	430.5	175.3		Ok
1988 MAY 12	BER 101141.9	61.008W	3.581E 15	2.3 BER 1.4 M1W
	DIST	AZIM		Comments.....
SUE	64.0	265.6		Ok
BER	118.4	106.8		Ok
HYA	141.7	264.0		Ok
KMY	220.7	335.9		Ok
BLS 14	254.7	316.4		Ok
1988 MAY 13	WOP 003731.0	66.800W	29.600E	3.1 WOP 2.8 M1W
	DIST	AZIM		Comments.....
ARCESS	349.1	149.0		Ok (3C)
ITK	363.3	129.7		Saturated
PRO	442.3	20.5		Ok
WORESS	111.7	44.5		Ok
1988 MAY 16	BER 235023.1	67.568W	21.380E 15 3.4 BER 3.3 BER	2.9 M1W
	DIST	AZIM		Comments.....
ARCESS	276.5	219.4		Ok (3C)
WORESS	897.4	27.8		Ok (3C)

1988 MAY 17	BER 002326.7	65.108W	6.003E	15 2.7	BER 3.1 BER	2.7 MLW
	DIST	AZIM			Comments.....	
MOL	292.9	345.6			Ok	
LOF	473.5	228.2			Ok (3C)	
WORESS	562.4	332.4			Ok (3C)	
ARCESS	967.7	248.8			Ok	
1988 MAY 23	BER 035528.0	57.466W	6.779E	15 2.9	BER 3.0 BER	2.8 MLW
	DIST	AZIM			Comments.....	
WORESS	454.8	218.9			Ok (3C)	
1988 MAY 28	HEL 145600.6	57.94 W	7.18 E	15	2.8 HEL	2.7 MLW
	DIST	AZIM			Comments.....	
ODD	222.0	171.5			Ok	
BER	292.5	157.9			Saturated	
HYA	363.8	170.7			Ok	
SUE	373.3	157.4			Ok	
O1A01	385.9	214.7			Low gain (LF)	
WORESS	398.0	220.5			Ok (3C)	
O3C00	440.4	214.7			Ok (LF)	
1988 JUN 02	BER 113555.6	62.057W	2.479E	15 3.0	BER 2.9 BER	3.0 MLW
	DIST	AZIM			Comments.....	
SUE	164.7	313.6			Clipped, processed	
HYA	220.4	298.4			Ok	
MOL	269.0	260.0			Ok	
ODD	325.2	317.8			Ok	
KMY	351.3	335.7			Ok	
BLS 14	380.1	323.3			Ok	
O1A01	468.0	290.4			Low gain (LF)	
O3C00	481.2	284.5			Ok (LF)	
WORESS	505.7	290.9			Ok (3C)	
1988 JUN 03	BER 060505.0	59.747W	5.568E	15 1.9	BER 2.4 BER	1.9 MLW
	DIST	AZIM			Comments.....	
KMY	62.3	16.8			Ok	
ODD	65.6	250.3			Ok	
BLS 14	81.5	299.7			Ok	
SUE	152.6	162.7			Ok, airgun noise	
HYA	161.7	192.4			Ok	
1988 JUN 08	BER 020331.6	66.560W	15.987E	15 2.6	BER 3.1 BER	2.1 MLW
	DIST	AZIM			Comments.....	
LOF	204.8	147.7			Ok (3C)	
TRO	363.9	201.0			Ok	
WORESS	685.3	16.8			Ok (3C)	
1988 JUN 27	BKH 75525.5	58.203W	11.022E	2	3.0 BER	2.3 MLW
	DIST	AZIM			Comments.....	
WORESS	283.6	186.2			Ok (3C)	
ODD	315.8	125.2			Ok	
HYA	427.7	138.4			Ok	
SUE	474.9	129.3			Ok	
1988 JUL 23	BER 070439.2	59.517W	5.608E	15 2.0	BER 2.4 BER	1.9 MLW
	DIST	AZIM			Comments.....	
KMY	39.7	31.0			Ok	
BLS 14	70.6	282.1			Ok	
ODD	76.7	231.5			Ok	
SUE	177.9	164.4			Ok	
HYA	186.5	190.1			Ok	
1988 JUL 30	BER 024142.2	61.218W	5.289E	15	2.3 BER	1.1 MLW
	DIST	AZIM			Comments.....	
SUE	33.6	57.5			Ok	
HYA	48.6	277.2			Ok	
ODD	160.2	332.5			Ok	
BLS 14	220.7	338.0			Ok	

1988 JUL 31	BER 090808.4 62.045W	2.415E 15 2.7	BER 2.8 BER	3.1 MLW
	DIST AZIM		Comments.....	
SUE	166.4 312.5		Clipped, processed	
HYA	222.8 297.7		Ok	
ODD	327.7 317.3		Ok	
KMY	351.6 335.1		Ok	
BLS 14	381.3 322.8		Ok, clipped in P-window	
1988 AUG 06	BER 035259.5 59.957W	6.319E 3 1.1	BER 2.2 BER	0.8 MLW
	DIST AZIM		Comments.....	
ODD	19.5 272.4		Ok	
BLS 14	69.4 335.8		Ok	
KMY	102.7 35.7		Ok	
HYA	134.9 176.9		Ok	
1988 AUG 08	BER 195934.0 63.672W	2.386E 11 4.8	WAO 4.0 BER 5.3	5 5.0 MLW
	DIST AZIM		Comments.....	
O1A01	541.9 309.2		Low gain (LF)	
WORESS	577.3 308.5		Ok (HF) (IP) (3C)	
TRO	983.0 235.6		Saturated	
ARCESS	1204.4 248.5		Ok (3C)	
1988 AUG 21	BER 145201.3 66.634W	12.477E 8	3.3 BER	2.3 MLW
	DIST AZIM		Comments.....	
LOF	173.0 195.5		Ok (3C)	
WSS	235.7 5.5		Ok	
TRO	428.3 221.8		Ok	
MOL	510.5 25.3		Ok	
ARCESS	630.2 245.4		Ok (3C)	
WORESS	659.2 3.6		Ok (3C)	
1988 SEP 01	BER 172838.4 66.970W	21.213E 2.4	BER 3.0 BER	M 2.1 MLW
	DIST AZIM		Comments.....	
ETK	242.8 201.3		Ok	
MOR	297.0 71.1		Ok	
TRO	311.6 161.3		Ok	
ARCESS	336.6 213.8		Ok (3C)	
LOF	352.2 108.0		Ok (3C)	
WSS	502.9 53.2		Ok	
1988 SEP 02	BER 181402.1 66.916W	20.808E 37 1.9	BER 3.0 BER	M 1.8 MLW
	DIST AZIM		Comments.....	
ETK	254.8 204.7		Ok	
MOR	278.4 71.5		Ok	
TRO	312.8 164.7		Ok	
ARCESS	350.8 215.9		Ok (3C)	
1988 SEP 17	BER 094947.4 61.420W	1.571E 18 2.8	BER 3.1 BER	2.9 MLW
	DIST AZIM		Comments.....	
SUE	176.0 284.7		Ok	
HYA	249.0 278.5		Ok	
KMY	319.0 322.0		Ok	
ODD	322.9 302.7		Ok	
MOL	338.3 250.4		Ok	
BLS 14	367.4 310.2		Ok	
WORESS	543.0 282.4		Ok (3C)	
LOF	936.5 222.8		Ok	
ETK	1308.3 240.4		Ok	
1988 SEP 28	BER 091600.0 61.420W	1.571E 18 2.8	BER 3.4 BER	2.0 MLW
	DIST AZIM		Comments.....	
TRO	370.7 251.9		Ok	
MOL	660.2 10.0		Ok	
WORESS	854.0 356.7		Ok	
1988 OCT 20	BER 214349.6 60.070W	6.420E 3.6	BER 3.8 BER	3.4 MLW
	DIST AZIM		Comments.....	

01A01	260.4	252.6				Low gain (LF)
WORESS	291.8	257.5				Ok (3C)
MOR	804.6	215.3				Ok
ARCESS	1379.5	229.7				Ok
1988 OCT 27	BKH 142216.7	66.892N	8.880E	25	3.8 HEL	3.4 MLW
	DIST	AZIM			Comments.....	
TRO	514.8	238.4			Ok	
HYA	651.6	10.4			Ok	
SUE	680.7	15.4			Ok	
WORESS	698.6	350.4			Ok (3C)	
BER	745.9	12.1			Ok	
ARCESS	746.3	254.7			Ok (3C)	
ODD	786.0	7.2			Ok	
BLS 14	842.5	6.1			Ok	
1988 OCT 27	BKH 224728.4	66.957N	8.824E	25	3.0 HEL	2.3 MLW
	DIST	AZIM			Comments.....	
LOF	239.4	239.0			Ok (3C)	
WSS	306.4	333.4			Ok	
MOL	492.9	6.5			Ok	
WORESS	706.2	350.3			Ok	
ARCESS	744.8	255.3			Ok	
1988 NOV 09	HEL 183252.0	67.1 N	20.6 E	0	2.3 HEL	M 2.3 MLW
	DIST	AZIM			Comments.....	
KTU	239.8	208.5			Ok	
ARCESS	338.5	219.0			Ok (3C)	
WORESS	835.5	28.1			Ok	
1988 NOV 29	BER 230342.0	67.958N	20.661E		3.0 BER	1.7 MLW
	DIST	AZIM			Comments.....	
KTU	157.8	223.1			Ok	
TRO	199.5	158.7			Ok	
ARCESS	263.3	230.4			Ok (3C)	
LOF	298.4	90.4			Ok (3C)	
WSS	545.8	41.7			Ok	
1988 DEC 06	HEL 162141.8	77.01 N	26.14 E	10	4.0 BER	3.7 MLW
	DIST	AZIM			Comments.....	
ARCESS	834.5	1.1			Ok (3C)	
TRO	853.6	12.2			Ok	
KTU	897.4	4.7			Ok	
LOF	1071.4	17.1			Ok	
MOR	1261.4	13.1			Ok	
WSS	1477.0	13.9			Ok	
1988 DEC 7	BER 182854.3	67.039N	21.480E	4 3.2	BER 2.0 BER	M 1.5 MLW
	DIST	AZIM			Comments.....	
KTU	231.9	199.3			Ok	
TRO	307.8	158.8			Ok	
MOR	310.1	70.2			Ok	
ARCESS	324.1	212.7			Ok	
WSS	516.8	53.0			Ok	
1988 DEC 15	BER 131038.7	57.816N	11.495E	0 3.1	BER 0.0	1.9 MLW
	DIST	AZIM			Comments.....	
WORESS	325.2	180.5			Ok (3C)	
ODD	366.0	128.4			Ok	
KMY	395.8	110.4			Ok	
HYA	479.0	138.8			Ok, much long-period noise	
MOL	572.9	155.8			Ok	
1988 DEC 15	BER 183003.0	66.833N	21.486E	2 3.2	BER 0.0	M 1.8 MLW
	DIST	AZIM			Comments.....	
KTU	253.8	197.6			Ok	
TRO	329.7	160.1			Ok	
ARCESS	344.3	210.8			Ok (3C)	

WSS	506.6	55.3					Ok
MOL	814.4	48.3					Ok, noisy (At quantum level)
1988 DEC 23	HEL	81843.0	67.6	■	34.2	E	0
	DIST	AZIM					3.4 BER M 3.3 MLW
KTk	478.3	104.0					Comments.....
							Ok
1988 DEC 24	BER	213052.3	68.575	■	12.787E	7	3.0
	DIST	AZIM					BER 2.1 BER 2.0 MLW
TR0	271.4	247.1					Comments.....
MOR	274.1	342.9					Ok
KTk	424.3	268.3					Ok
ARCESS	517.8	264.1					Ok, noisy
MOL	711.3	17.5					Ok
1988 DEC 31	BER	140059.0	69.903	■	31.254E	13	3.7
	DIST	AZIM					BER 2.8 BER M 2.8 MLW
ARCESS	226.1	76.9					Comments.....
KTk	329.3	68.7					Ok, Rg phase present (3C)
TR0	476.1	80.6					Ok
MOL	1329.3	42.0					Ok, noisy (at quantum level)
WORESS	1362.1	33.3					Ok
1989 JAN 2	BER	182932.4	67.093	■	21.012E	0	3.2
	DIST	AZIM					BER 0.0 M 1.9 MLW
KTk	233.2	204.5					Comments.....
MOR	292.0	68.1					Ok
TR0	296.0	162.2					Ok
ARCESS	329.3	216.3					Ok (3C)
1989 JAN 6	BER	120731.7	67.923	■	34.447E	15	3.7
	DIST	AZIM					BER 0.0 M 3.1 MLW
ARCESS	403.8	112.2					Comments.....
KTk	474.4	99.5					Ok (3C)
TR0	653.5	99.6					Ok
MOR	872.0	68.7					Ok
1989 JAN 10	BER	110530.4	60.825	■	4.849E	1	4.5
	DIST	AZIM					BER 0.0 1.3 MLW
WORESS	364.6	274.5					Comments.....
							Ok
1989 JAN 13	BER	41824.6	62.852	■	6.262E	0	3.3
	DIST	AZIM					BER 0.0 2.7 MLW
SUF	215.0	20.8					Comments.....
ODD	324.1	356.3					Ok
WSS	338.5	239.0					Ok
WORESS	364.8	312.6					Ok (3C)
BLS 14	387.0	355.7					Ok
KMY	409.3	7.3					Ok
MOR	555.1	231.1					Ok
1989 JAN 15	BER	10	62.2	■	21.501E	0	3.2
	DIST	AZIM					BER 0.0 M 2.0 MLW
KTk	255.3	197.3					Comments.....
MOR	306.4	74.8					Ok
TR0	331.1	160.1					Ok
ARCESS	345.6	210.6					Ok (3C)
WSS	506.6	55.6					Ok
1989 JAN 16	BER	21461.1	67.354	■	321.1	1	3.5
	DIST	AZIM					BER 0.0 2.1 MLW
TR0	637.1	281.1					Comments.....
MOR	687.5	317.5					Ok
WSS	768.6	332.0					Ok
1989 JAN 20	BER	93346.2	57.618	■	9.479E	10	3.1
	DIST	AZIM					BER 0.0 4.0 MLW
01401	384.7	202.0					Comments.....
							Low gain (1.1)

NORESS	388.8	208.1				Ok (3C)
HYA	416.1	160.8				Ok
SUE	437.5	149.5				Ok
ARCESS	1562.7	220.4				Ok (3C)
1989 JAN 20	BER 182953.1	66.969W	21.640E	2 3.2	BER 0.0	M 2.0 MLW
	DIST	AZIM			Comments.....	
RTK	237.3	197.1				Ok
MOR	315.2	71.9				Ok
TRO	317.5	158.1				Ok
ARCESS	327.7	211.0				Ok (3C)
LOF	369.2	106.8				Ok
NSS	519.4	54.1				No P-arrival
1989 JAN 23	BER 140628.5	61.952W	4.404E	29 4.9	BER 0.0	5.1 4.8 MLW
	DIST	AZIM			Comments.....	
NORESS	405.1	292.7				Ok (HF) (IP) (3C)
LOF	810.2	216.1				Ok (3C)
TRO	1078.5	224.6				Ok
RTK	1166.3	236.8				Ok
ARCESS	1273.3	238.9				Ok (3C)
1989 JAN 29	BER 163822.2	59.651W	6.016E	0 4.2	BER 4.6	NAO 4.4 MLW
	DIST	AZIM			Comments.....	
OSG	198.6	117.0				Saturated
O1A01	300.6	245.9				Low gain (LF)
NORESS	329.3	250.9				Ok (HF) (IP) (3C)
NSS	625.9	212.4				Ok
ARCESS	1431.1	229.4				Ok (3C)
1989 FEB 14	BER 204422.3	61.050W	3.943E	21 2.8	BER 3.0	BER 3.0 MLW
	DIST	AZIM			Comments.....	
O1A01	376.9	276.5				Low gain (LF)
O3C00	402.8	269.9				Ok (LF)
NORESS	413.8	278.2				Ok (3C)
1989 FEB 21	BER 254 3.1	65.336W	29.310E	5 4.2	BER 3.2	BER 2.9 MLW
	DIST	AZIM			Comments.....	
RTK	486.5	144.5				No P-arrival
ARCESS	495.6	159.0				Ok (3C)
TRO	651.6	132.3				Ok
LOF	760.0	106.7				Ok (3C)
NORESS	1030.2	52.6				Ok (3C)
1989 FEB 26	HEL 33349.0	67.6 W	34.0 E	0	3.1 HEL	M 3.1 MLW
	DIST	AZIM			Comments.....	
ARCESS	407.7	117.9				Ok (3C)
RTK	470.6	104.5				Ok
TRO	652.1	103.2				Ok
LOF	859.4	84.4				Ok (3C)
NORESS	1321.8	45.2				Ok (3C)
1989 FEB 28	BER 183648.9	66.889W	21.571E	0 3.4	BER 2.2	BER M 2.1 MLW
	DIST	AZIM			Comments.....	
RTK	246.7	197.2				Ok
TRO	324.9	159.1				Ok
ARCESS	337.0	210.8				Ok (3C)
1989 MAR 3	BER 1049 3.2	60.632W	6.321E	4 3.2	BER 0.0	1.1 MLW
	DIST	AZIM			Comments.....	
HYA	59.9	173.0				Ok
ODD	78.4	346.0				Ok
SUE	97.1	118.5				Ok
BLS 14	141.2	348.7				Ok
KMY	169.2	20.3				Ok
1989 MAR 11	BER 1738 2.8	67.187W	13.408E	21 3.0	BER 0.0	1.8 MLW
	DIST	AZIM			Comments.....	

LUF	105.5	182.7				Ok (3C)	
WSS	303.4	11.9				Ok	
TRU	354.5	222.3				Ok, noisy	
RTK	456.4	248.2				Ok	
ARCESS	561.4	248.0				Ok, noisy	
MOL	564.3	25.7				Ok, noisy	
1989 MAR 26	BER	65042.8	66.541W	13.440E	18 3.1	BER 1.8 BER	1.9 MLW
	DIST	AZIM				Comments.....	
LUF	177.5	181.2				Ok (3C)	
TRU	413.5	216.1				Ok, noisy	
RTA	496.1	240.9				Ok	
MOL	524.7	29.9				Ok	
ARCESS	602.9	242.2				Ok	
1989 MAR 26	BKH	92910.0	72.950W	5.351E	8	4.2 HEL	2.9 MLW
	DIST	AZIM				Comments.....	
TRU	608.8	313.6				Ok	
LUF	616.4	334.3				Ok (3C)	
RTK	780.6	312.3				Ok	
ARCESS	812.4	307.1				Ok (3C)	
1989 MAR 26	BER	105938.9	72.430W	9.219E	1 3.3	BER 0.0	2.1 MLW
	DIST	AZIM				Comments.....	
TRU	469.7	316.1				Ok	
LUF	505.9	343.3				Ok (3C)	
RTK	639.8	312.9				Ok	
ARCESS	671.9	306.1				Ok	
1989 MAR 30	BER	145112.3	72.500W	8.450E	0 3.1	BER 0.0	2.3 MLW
	DIST	AZIM				Comments.....	
TRU	495.3	315.0				Ok	
LUF	522.9	341.0				Ok (3C)	
ARCESS	698.9	306.0				Ok	
1989 APR 09	BKH	44548.8	67.614W	33.860E	0	2.7 HEL M	2.5 MLW
	DIST	AZIM				Comments.....	
RTA	464.5	104.6				Ok, Rg phase present	
1989 APR 13	BER	234521.7	70.040W	9.515E	0 3.1	CBER 0.0	2.2 MLW
	DIST	AZIM				Comments.....	
TRU	364.7	281.5				No P-arrival	
1989 APR 16	BER	41113.4	66.631W	5.865E	13 3.1	CBER 2.9LBER	2.4 MLW
	DIST	AZIM				Comments.....	
LUF	368.7	246.6				Ok, short Lg-window	
RTA	775.6	258.3				Ok, short Lg-window	
1989 APR 16	HEL	63443.6	67.58 W	33.68 E	10	4.1 HEL	3.8 MLW
	DIST	AZIM				Comments.....	
RTA	459.7	105.7				Ok	
LUF	846.7	84.8				Ok (3C)	
1989 APR 22	BER	180310.7	67.380W	33.893E	15 3.9	CBER 0.0 M	3.0 MLW
	DIST	AZIM				Comments.....	
RTA	477.7	107.7				Ok	
TRU	659.6	105.2				Ok	
MOR	846.9	72.7				Ok	
LUF	861.0	86.1				Ok, noisy	
WSS	1040.0	62.5				Ok, noisy	
1989 APR 11	BER	34.7	34.7	34.7	34.7	3.3 BER	2.5 MLW
	DIST	AZIM				Comments.....	
LUF	186.3	184.8				Ok (3C)	
WSS	221.6	14.1				Ok	
TRU	426.5	216.8				Ok	
MOL	509.4	29.5				Ok	
RTA	511.9	240.9				Ok	

1989 MAY 18	BER	33640.6	65.938N	8.039E	16	3.0CBER 0.0	2.4	MLW
	DIST	AZIM				Comments.....		
WSS		241.5	312.3			Ok		
MOR		306.2	266.8			Ok		
MOL		376.2	3.4			Ok		
1989 MAY 19	BER	61658.9	68.539N	11.107E	15	3.1CBER 0.0	2.5	MLW
	DIST	AZIM				Comments.....		
MOR		300.8	330.2			Ok		
TRO		334.5	252.3			Ok		
WSS		448.6	355.5			Ok		
KTK		492.3	269.5			Ok		
MOL		685.3	12.3			Ok		
1989 MAY 19	BKH	111939.2	69.431N	31.557E	0	3.1 BER	M	2.6 MLW
	DIST	AZIM				Comments.....		
KTK		332.6	78.0			Ok		
TRO		492.7	86.7			Ok		
1989 MAY 22	HEL	121501.6	63.19 N	21.42 E	10	3.2 HEL		2.5 MLW
	DIST	AZIM				Comments.....		
MOR		464.4	133.9			Ok		
WSS		487.8	103.5			Ok		
1989 MAY 25	BER	172921.8	67.099N	20.433E	28	3.0CBER 0.0	M	2.0 MLW
	DIST	AZIM				Comments.....		
MOR		268.1	66.4			Ok		
TRO		289.3	166.9			Ok		
LOF		315.3	108.2			Ok (3C)		
WSS		480.9	49.7			Ok		

CONTRACTORS (United States)

Prof. Thomas Albrecht
Seismological Lab, 252-21
Division of Geological & Planetary Sciences
California Institute of Technology
Pasadena, CA 91125

Prof. Charles B. Archambeau
CIRES
University of Colorado
Boulder, CO 80309

Dr. Thomas C. Bache, Jr.
Science Applications Int'l Corp.
10260 Campus Point Drive
San Diego, CA 92121 (2 copies)

Prof. Muawia Barazangi
Institute for the Study of the Continent
Cornell University
Ithaca, NY 14853

Dr. Douglas R. Baumgardt
ENSCO, Inc.
5400 Port Royal Road
Springfield, VA 22151-2388

Prof. Jonathan Berger
IGPP, A-025
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093

Dr. Lawrence J. Burdick
Woodward-Clyde Consultants
566 El Dorado Street
Pasadena, CA 91109-3245

Dr. E. Coyne
New England Research, Inc.
76 O'Brien Drive
Waterbury Junction, VT 05601

Prof. Vernon F. Cormier
Department of Geology & Geophysics
University Room 207
The University of Connecticut
Storrs, CT 06268

Professor Anton W. Dainty
Earth Resources Laboratory
Massachusetts Institute of Technology
42 Carlisle Street
Cambridge, MA 02142

Prof. Steven Day
Department of Geological Sciences
San Diego State University
San Diego, CA 92182

Dr. Zoltan A. Der
ENSCO, Inc.
5400 Port Royal Road
Springfield, VA 22151-2388

Prof. John Ferguson
Center for Lithospheric Studies
The University of Texas at Dallas
P.O. Box 830688
Richardson, TX 75083-0688

Prof. Stanley Flatte
Applied Sciences Building
University of California
Santa Cruz, CA 95064

Dr. Alexander Florence
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025-3493

Prof. Stephen Grand
University of Texas at Austin
Department of Geological Sciences
Austin, TX 78713-7909

Prof. Henry L. Gray
Vice Provost and Dean
Department of Statistical Sciences
Southern Methodist University
Dallas, TX 75275

Dr. Indira Gupta
Teledyne Geotech
314 Montgomery Street
Alexandria, VA 22304

Prof. David G. Harkrider
Seismological Laboratory
Division of Geological & Planetary Sciences
California Institute of Technology
Pasadena, CA 91125

Prof. Donald V. Helmberger
Seismological Laboratory
Division of Geological & Planetary Sciences
California Institute of Technology
Pasadena, CA 91125

Prof. Eugene Herrin
Institute for the Study of Earth and Man
Geophysical Laboratory
Southern Methodist University
Dallas, TX 75275

Prof. Robert B. Herrmann
Department of Earth & Atmospheric Sciences
St. Louis University
St. Louis, MO 63156

Prof. Bryan Isacks
Cornell University
Department of Geological Sciences
SNEE Hall
Ithaca, NY 14850

Dr. Rong-Song Jih
Teledyne Geotech
314 Montgomery Street
Alexandria, VA 22314

Prof. Lane R. Johnson
Seismographic Station
University of California
Berkeley, CA 94720

Prof. Alan Kafka
Department of Geology & Geophysics
Boston College
Chestnut Hill, MA 02167

Dr. Richard LaCoss
MIT-Lincoln Laboratory
M-200B
P. O. Box 73
Lexington, MA 02173-0073 (3 copies)

Prof. Fred K. Lamb
University of Illinois at Urbana-Champaign
Department of Physics
1110 West Green Street
Urbana, IL 61801

Prof. Charles A. Langston
Geosciences Department
403 Deike Building
The Pennsylvania State University
University Park, PA 16802

Prof. Thorne Lay
Institute of Tectonics
Earth Science Board
University of California, Santa Cruz
Santa Cruz, CA 95064

Prof. Arthur Lerner-Lam
Lamont-Doherty Geological Observatory
of Columbia University
Palisades, NY 10964

Dr. Christopher Lynnes
Teledyne Geotech
314 Montgomery Street
Alexandria, VA 22314

Prof. Peter Malin
University of California at Santa Barbara
Institute for Crustal Studies
Santa Barbara, CA 93106

Dr. Randolph Martin, III
New England Research, Inc.
76 Olcott Drive
White River Junction, VT 05001

Dr. Gary McCartor
Mission Research Corporation
735 State Street
P.O. Drawer 719
Santa Barbara, CA 93102 (2 copies)

Prof. Thomas V. McEvilly
Seismographic Station
University of California
Berkeley, CA 94720

Dr. Keith L. McLaughlin
S-CUBED
A Division of Maxwell Laboratory
P.O. Box 1620
La Jolla, CA 92038-1620

Prof. William Menke
Lamont-Doherty Geological Observatory
of Columbia University
Palisades, NY 10964

Stephen Miller
SRI International
333 Ravenswood Avenue
Box AF 116
Menlo Park, CA 94025-3493

Prof. Bernard Minster
IGPP, A-025
Scripps Institute of Oceanography
University of California, San Diego
La Jolla, CA 92093

Prof. Brian J. Mitchell
Department of Earth & Atmospheric Sciences
St. Louis University
St. Louis, MO 63156

Prof. David G. Simpson
Lamont-Doherty Geological Observatory
of Columbia University
Palisades, NY 10964

Mr. Jack Murphy
S-CUBED, A Division of Maxwell Laboratory
11800 Sunrise Valley Drive
Suite 1212
Reston, VA 22091 (2 copies)

Dr. Jeffrey Stevens
S-CUBED
A Division of Maxwell Laboratory
P.O. Box 1620
La Jolla, CA 92038-1620

Dr. Bao Nguyen
GL/LWH
Hanscom AFB, MA 01731-5000

Prof. Brian Stump
Institute for the Study of Earth & Man
Geophysical Laboratory
Southern Methodist University
Dallas, TX 75275

Prof. John A. Orcutt
IGPP, A-025
Scripps Institute of Oceanography
University of California, San Diego
La Jolla, CA 92093

Prof. Jeremiah Sullivan
University of Illinois at Urbana-Champaign
Department of Physics
1110 West Green Street
Urbana, IL 61801

Prof. Keith Priestley
University of Cambridge
Bullard Labs, Dept. of Earth Sciences
Madingley Rise, Madingley Rd.
Cambridge CB3 0EZ, ENGLAND

Prof. Clifford Thurber
University of Wisconsin-Madison
Department of Geology & Geophysics
1215 West Dayton Street
Madison, WI 53706

Prof. Paul G. Richards
L-210
Lawrence Livermore National Laboratory
Livermore, CA 94550

Prof. M. Nafi Toksoz
Earth Resources Lab
Massachusetts Institute of Technology
42 Carleton Street
Cambridge, MA 02142

Dr. Wilmer Rivers
Teledyne Geotech
314 Montgomery Street
Alexandria, VA 22314

Prof. John E. Vidale
University of California at Santa Cruz
Seismological Laboratory
Santa Cruz, CA 95064

Prof. Charles C. Sammis
Center for Earth Sciences
University of Southern California
University Park
Los Angeles, CA 90089-0741

Prof. Terry C. Wallace
Department of Geosciences
Building #77
University of Arizona
Tucson, AZ 85721

Prof. Christopher H. Scholz
Lamont-Doherty Geological Observatory
of Columbia University
Palisades, NY 10964

Dr. Raymond Willeman
GL/LWH
Hanscom AFB, MA 01731-5000

Thomas J. Sereno, Jr.
Science Application Inc./Corr
10260 Channing Point Drive
San Diego, CA 92121

Dr. Lorraine Wolf
GL/LWH
Hanscom AFB, MA 01731-5000

OTHERS (United States)

Dr. Monem Abdel-Gawad
Rockwell International Science Center
1049 Camino Dos Rios
Thousand Oaks, CA 91360

Prof. Keiiti Aki
Center for Earth Sciences
University of Southern California
University Park
Los Angeles, CA 90089-0741

Prof. Shelton S. Alexander
Geosciences Department
403 Deike Building
The Pennsylvania State University
University Park, PA 16802

Dr. Kenneth Anderson
BBNSTC
Mail Stop 14/1B
Cambridge, MA 02238

Dr. Ralph Archuleta
Department of Geological Sciences
University of California at Santa Barbara
Santa Barbara, CA 93102

J. Barker
Department of Geological Sciences
State University of New York
at Binghamton
Vestal, NY 13901

Dr. T.J. Bennett
S-CUBED
A Division of Maxwell Laboratory
11800 Sunrise Valley Drive, Suite 1212
Reston, VA 22091

Mr. William J. Best
907 Westwood Drive
Vienna, VA 22180

Dr. N. Biswas
Geophysical Institute
University of Alaska
Fairbanks, AK 99701

Dr. G.A. Bollinger
Department of Geological Sciences
Virginia Polytechnical Institute
21044 Derring Hall
Blacksburg, VA 24061

Dr. Stephen Bratt
Center for Seismic Studies
1300 North 17th Street
Suite 1450
Arlington, VA 22209

Michael Browne
Teledyne Geotech
3401 Shiloh Road
Garland, TX 75041

Mr. Roy Burger
1221 Serry Road
Schenectady, NY 12309

Dr. Robert Burrige
Schlumberger-Doll Research Center
Old Quarry Road
Ridgefield, CT 06877

Dr. Jerry Carter
Rondout Associates
P.O. Box 224
Stone Ridge, NY 12484

Dr. W. Winston Chan
Teledyne Geotech
314 Montgomery Street
Alexandria, VA 22314-1581

Dr. Theodore Cherry
Science Horizons, Inc.
710 Encinitas Blvd., Suite 200
Encinitas, CA 92024 (2 copies)

Prof. Jon F. Claerbout
Department of Geophysics
Stanford University
Stanford, CA 94305

Prof. Robert W. Clayton
Seismological Laboratory
Division of Geological & Planetary Sciences
California Institute of Technology
Pasadena, CA 91125

Prof. F. A. Dahlen
Geological and Geophysical Sciences
Princeton University
Princeton, NJ 08544-0636

Prof. Adam Dziewonski
Hoffman Laboratory
Harvard University
20 Oxford St
Cambridge, MA 02138

Prof. John Ebel
Department of Geology & Geophysics
Boston College
Chestnut Hill, MA 02167

Eric Fielding
SNEE Hall
INSTOC
Cornell University
Ithaca, NY 14853

Prof. Donald Forsyth
Department of Geological Sciences
Brown University
Providence, RI 02912

Dr. Cliff Frolich
Institute of Geophysics
8701 North Mopac
Austin, TX 78759

Dr. Anthony Gangi
Texas A&M University
Department of Geophysics
College Station, TX 77843

Dr. Freeman Gilbert
Inst. of Geophysics & Planetary Physics
University of California, San Diego
P.O. Box 109
La Jolla, CA 92037

Mr. Edward Giller
Pacific Sierra Research Corp.
1401 Wilson Boulevard
Arlington, VA 22209

Dr. Jeffrey W. Given
SAIC
10260 Campus Point Drive
San Diego, CA 92121

Prof. Roy Greenfield
Geosciences Department
403 Deike Building
The Pennsylvania State University
University Park, PA 16802

Dan N. Hagedorn
Battelle
Pacific Northwest Laboratories
Battelle Boulevard
Richland, WA 99352

Kevin Hutchenson
Department of Earth Sciences
St. Louis University
3507 Laclede
St. Louis, MO 63103

Prof. Thomas H. Jordan
Department of Earth, Atmospheric
and Planetary Sciences
Massachusetts Institute of Technology
Cambridge, MA 02139

Robert C. Kemerait
ENSCO, Inc.
445 Pineda Court
Melbourne, FL 32940

William Kikendall
Teledyne Geotech
3401 Shiloh Road
Garland, TX 75041

Prof. Leon Knopoff
University of California
Institute of Geophysics & Planetary Physics
Los Angeles, CA 90024

Prof. L. Timothy Long
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, GA 30332

Prof. Art McGarr
Mail Stop 977
Geological Survey
345 Middlefield Rd.
Menlo Park, CA 94025

Dr. George Mellman
Sierra Geophysics
11255 Kirkland Way
Kirkland, WA 98033

Prof. John Nabelek
College of Oceanography
Oregon State University
Corvallis, OR 97331

Prof. Geza Nagy
University of California, San Diego
Department of Ames, M.S. B-010
La Jolla, CA 92093

Prof. Amos Nur
Department of Geophysics
Stanford University
Stanford, CA 94305

Prof. Jack Oliver
Department of Geology
Cornell University
Ithaca, NY 14850

Prof. Robert Phinney
Geological & Geophysical Sciences
Princeton University
Princeton, NJ 08544-0636

Dr. Paul Pomeroy
Rondout Associates
P.O. Box 224
Stone Ridge, NY 12484

Dr. Jay Pulli
RADIX System, Inc.
2 Taft Court, Suite 203
Rockville, MD 20850

Dr. Norton Rimer
S-CUBED
A Division of Maxwell Laboratory
P.O. Box 1620
La Jolla, CA 92038-1620

Prof. Larry J. Ruff
Department of Geological Sciences
1006 C.C. Little Building
University of Michigan
Ann Arbor, MI 48109-1063

Dr. Richard Sailor
TASC Inc.
55 Walkers Brook Drive
Reading, MA 01867

John Sherwin
Teledyne Geotech
3401 Shiloh Road
Garland, TX 75041

Prof. Robert Smith
Department of Geophysics
University of Utah
1400 East 2nd South
Salt Lake City, UT 84112

Prof. S. W. Smith
Geophysics Program
University of Washington
Seattle, WA 98195

Dr. Stewart W. Smith
Geophysics AK-50
University of Washington
Seattle, WA 98195

Dr. George Sutton
Rondout Associates
P.O. Box 224
Stone Ridge, NY 12484

Prof. L. Sykes
Lamont-Doherty Geological Observatory
of Columbia University
Palisades, NY 10964

Prof. Pradeep Talwani
Department of Geological Sciences
University of South Carolina
Columbia, SC 29208

Prof. Ta-liang Teng
Center for Earth Sciences
University of Southern California
University Park
Los Angeles, CA 90089-0741

Dr. R.B. Tittmann
Rockwell International Science Center
1049 Camino Dos Rios
P.O. Box 1085
Thousand Oaks, CA 91360

Dr. Gregory van der Vink
IRIS, Inc.
1616 North Fort Myer Drive
Suite 1440
Arlington, VA 22209

Professor Daniel Walker
University of Hawaii
Institute of Geophysics
Honolulu, HI 96822

William R. Walter
Seismological Laboratory
University of Nevada
Reno, NV 89557

Dr. Gregory Wojcik
Weidlinger Associates
4410 El Camino Real
Suite 110
Los Altos, CA 94022

Prof. John H. Woodhouse
Hoffman Laboratory
Harvard University
20 Oxford St.
Cambridge, MA 02138

Prof. Francis T. Wu
Department of Geological Sciences
State University of New York
at Binghamton
Vestal, NY 13901

Dr. Gregory B. Young
ENSCO, Inc.
5400 Port Royal Road
Springfield, VA 22151-2388

GOVERNMENT

Dr. Ralph Alewine III
DARPA/NMRO
1400 Wilson Boulevard
Arlington, VA 22209-2308

Mr. James C. Battis
GL/LWH
Hanscom AFB, MA 01731-5000

Dr. Robert Blandford
DARPA/NMRO
1400 Wilson Boulevard
Arlington, VA 22209-2308

Eric Chael
Division 9241
Sandia Laboratory
Albuquerque, NM 87185

Dr. John J. Cipar
GL/LWH
Hanscom AFB, MA 01731-5000

Mr. Jeff Duncan
Office of Congressman Markey
2133 Rayburn House Bldg.
Washington, DC 20515

Dr. Jack Evernden
USGS - Earthquake Studies
345 Middlefield Road
Menlo Park, CA 94025

Art Frankel
USGS
922 National Center
Reston, VA 22092

Dr. T. Hanks
USGS
Nat'l Earthquake Research Center
345 Middlefield Road
Menlo Park, CA 94025

Dr. James Hannon
Lawrence Livermore Nat'l Laboratory
P.O. Box 808
Livermore, CA 94550

Paul Johnson
ESS-4, Mail Stop J979
Los Alamos National Laboratory
Los Alamos, NM 87545

Janet Johnston
GL/LWH
Hanscom AFB, MA 01731-5000

Dr. Katharine Kadinsky-Cade
GL/LWH
Hanscom AFB, MA 01731-5000

Ms. Ann Kerr
IGPP, A-025
Scripps Institute of Oceanography
University of California, San Diego
La Jolla, CA 92093

Dr. Max Koontz
US Dept of Energy/DP 5
Forrestal Building
1000 Independence Avenue
Washington, DC 20585

Dr. W.H.K. Lee
Office of Earthquakes, Volcanoes,
& Engineering
345 Middlefield Road
Menlo Park, CA 94025

Dr. William Leith
U.S. Geological Survey
Mail Stop 928
Reston, VA 22092

Dr. Richard Lewis
Director, Earthquake Engineering & Geophysics
U.S. Army Corps of Engineers
Box 631
Vicksburg, MS 39180

James F. Lewkowicz
GL/LWH
Hanscom AFB, MA 01731-5000

Mr. Alfred Lieberman
ACDA/VI-OA'State Department Bldg
Room 5726
320 - 21st Street, NW
Washington, DC 20451

Stephen Mangino
GL/LWH
Hanscom AFB, MA 01731-5000

Dr. Frank F. Pilotte
HQ AFTAC/TT
Patrick AFB, FL 32925-6001

Dr. Robert Masse
Box 25046, Mail Stop 967
Denver Federal Center
Denver, CO 80225

Katie Poley
CIA-OSWR/NED
Washington, DC 20505

Art McGarr
U.S. Geological Survey, MS-977
345 Middlefield Road
Menlo Park, CA 94025

Mr. Jack Rachlin
U.S. Geological Survey
Geology, Rm 3 C136
Mail Stop 928 National Center
Reston, VA 22092

Richard Morrow
ACDA/VI, Room 5741
320 21st Street N.W.
Washington, DC 20451

Dr. Robert Reinke
WL/NTESG
Kirtland AFB, NM 87117-6008

Dr. Keith K. Nakanishi
Lawrence Livermore National Laboratory
P.O. Box 808, L-205
Livermore, CA 94550

Dr. Byron Ristvet
HQ DNA, Nevada Operations Office
Attn: NVCG
P.O. Box 98539
Las Vegas, NV 89193

Dr. Carl Newton
Los Alamos National Laboratory
P.O. Box 1663
Mail Stop C335, Group ESS-3
Los Alamos, NM 87545

Dr. George Rothe
HQ AFTAC/TTR
Patrick AFB, FL 32925-6001

Dr. Kenneth H. Olsen
Los Alamos Scientific Laboratory
P.O. Box 1663
Mail Stop C335, Group ESS-3
Los Alamos, NM 87545

Dr. Alan S. Ryall, Jr.
DARPA/NMRO
1400 Wilson Boulevard
Arlington, VA 22209-2308

Howard J. Patton
Lawrence Livermore National Laboratory
P.O. Box 808, L-205
Livermore, CA 94550

Dr. Michael Shore
Defense Nuclear Agency/SPSS
6801 Telegraph Road
Alexandria, VA 22310

Mr. Chris Paine
Office of Senator Kennedy
SR 315
United States Senate
Washington, DC 20510

Dr. Albert Smith
Los Alamos National Laboratory
L-205
P. O. Box 808
Livermore, CA 94550

Colonel Jerry J. Perrizo
AFOSF/NP, Building 410
Boiling AFB
Washington, DC 20332-6448

Donald L. Springer
Lawrence Livermore National Laboratory
L-205
P. O. Box 808
Livermore, CA 94550

Mr. Charles L. Taylor
GL/LWG
Hanscom AFB, MA 01731-5000

DARPA/RMO/Security Office
1400 Wilson Boulevard
Arlington, VA 22209

Mr. Steven R. Taylor
Lawrence Livermore National Laboratory
L-205
P. O. Box 808
Livermore, CA 94550

Geophysics Laboratory
Attn: XO
Hanscom AFB, MA 01731-5000

Dr. Eileen Vergino
Lawrence Livermore National Laboratory
L-205
P. O. Box 808
Livermore, CA 94550

Geophysics Laboratory
Attn: LW
Hanscom AFB, MA 01731-5000

Dr. Thomas Weaver
Los Alamos National Laboratory
P.O. Box 1663, Mail Stop C335
Los Alamos, NM 87545

DARPA/PM
1400 Wilson Boulevard
Arlington, VA 22209

J.J. Zucca
Lawrence Livermore National Laboratory
P. O. Box 808
Livermore, CA 94550

Defense Technical Information Center
Cameron Station
Alexandria, VA 22314 (2 copies)

GL/SULL
Research Library
Hanscom AFB, MA 01731-5000 (2 copies)

Defense Intelligence Agency
Directorate for Scientific
& Technical Intelligence Attn: DT1B
Washington, DC 20340-6158

Secretary of the Air Force
(SAFRD)
Washington, DC 20330

AFTAC/CA
(STINFO)
Patrick AFB, FL 32925-6001

Office of the Secretary Defense
DDR & E
Washington, DC 20330

TACTEC
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201 (Final Report Only)

HQ DNA
Attn: Technical Library
Washington, DC 20305

DARPA/RMO/RETRIEVAL
1400 Wilson Boulevard
Arlington, VA 22209

CONTRACTORS (Foreign)

Dr. Ramon Cabre, S.J.
Observatorio San Calixto
Casilla 5939
La Paz, Bolivia

Prof. Hans-Peter Harjes
Institute for Geophysik
Ruhr University/Bochum
P.O. Box 102148
4630 Bochum 1, FRG

Prof. Eystein Husebye
NTNF/NORSAR
P.O. Box 51
N-2007 Kjeller, NORWAY

Prof. Brian L.N. Kennett
Research School of Earth Sciences
Institute of Advanced Studies
G.P.O. Box 4
Canberra 2601, AUSTRALIA

Dr. Bernard Massinon
Societe Radiomana
27 rue Claude Bernard
75005 Paris, FRANCE (2 Copies)

Dr. Pierre Mecheler
Societe Radiomana
27 rue Claude Bernard
75005 Paris, FRANCE

Dr. Svein Mykkeltveit
NTNF/NORSAR
P.O. Box 51
N-2007 Kjeller, NORWAY

FOREIGN (Others)

Dr. Peter Basham
Earth Physics Branch
Geological Survey of Canada
1 Observatory Crescent
Ottawa, Ontario, CANADA K1A 0Y3

Dr. Eduard Berg
Institute of Geophysics
University of Hawaii
Honolulu, HI 96822

Dr. Michel Bouchon
I.R.I.G.M.-B.P. 68
38402 St. Martin D'Heres
Cedex, FRANCE

Dr. Hilmar Bungum
NTNF/NORSAR
P.O. Box 51
N-2007 Kjeller, NORWAY

Dr. Michel Campillo
Observatoire de Grenoble
I.R.I.G.M.-B.P. 53
38041 Grenoble, FRANCE

Dr. Kin Yip Chun
Geophysics Division
Physics Department
University of Toronto
Ontario, CANADA M5S 1A7

Dr. Alan Douglas
Ministry of Defense
Blacknest, Brimpton
Reading RG7-4RS, UNITED KINGDOM

Dr. Roger Hansen
NTNF/NORSAR
P.O. Box 51
N-2007 Kjeller, NORWAY

Dr. Manfred Henger
Federal Institute for Geosciences & Nat'l Res.
Postfach 510153
D-3000 Hanover 51, FRG

Ms. Eva Johannisson
Senior Research Officer
National Defense Research Inst.
P.O. Box 27322
S-102 54 Stockholm, SWEDEN

Dr. Fekadu Kebede
Seismological Section
Box 12019
S-750 Uppsala, SWEDEN

Dr. Tormod Kvaerna
NTNF/NORSAR
P.O. Box 51
N-2007 Kjeller, NORWAY

Dr. Peter Marshal
Procurement Executive
Ministry of Defense
Blacknest, Brimpton
Reading FG7-4RS, UNITED KINGDOM

Prof. Ari Ben-Menahem
Department of Applied Mathematics
Weizman Institute of Science
Rehovot, ISRAEL 951729

Dr. Robert North
Geophysics Division
Geological Survey of Canada
1 Observatory Crescent
Ottawa, Ontario, CANADA K1A 0Y3

Dr. Frode Ringdal
NTNF/NORSAR
P.O. Box 51
N-2007 Kjeller, NORWAY

Dr. Jorg Schlittenhardt
Federal Institute for Geosciences & Nat'l Res.
Postfach 510153
D-3000 Hannover 51, FEDERAL REPUBLIC OF
GERMANY