EARTHQUAKE HAZARD STUDIES IN NORTHEASTERN UNITED STATES

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INVESTIGATIONS

The Lamont-Doherty Seismic Network

During the past decade Lamont-Doherty Geological Observatory has been operating a network of short period seismic stations in the states of New York, New Jersey, and Vermont. The present configuration of this network (Figure 1) consists of 38 stations. Of these 38 stations, 37 have single-component vertical seismometers and one (RAMA - Ramapo Mountain, New Jersey) is a three-component site. The signals are telemetered by telephone line and radio to a central recording site at Palisades, New York, and recorded on a common time base. Twenty-eight channels are recorded on two develocorders and all are recorded on an analogue magnetic tape recorder. Seven helicorders are used to monitor activity in real time, enabling rapid detection of earthquakes. The magnetic tapes are digitized for detailed analysis of the wave forms of particular events.

In addition to these 38 stations three SMA-1 strong motion accelerographs are presently deployed in the field. Sites for these instruments have been chosen in each of the three seismically active regions of New York State -- southeastern New York, the northern New York Adirondacks, and western New York (see Figure 2). Portable seismographs have also been deployed in the field on numerous occasions to supplement the permanent network and to study aftershock activity.

Data for local events recorded by this network as well as other stations in New England and adjacent Canada are analyzed to study the earthquake hazard, the seismicity, the relationship of earthquakes to

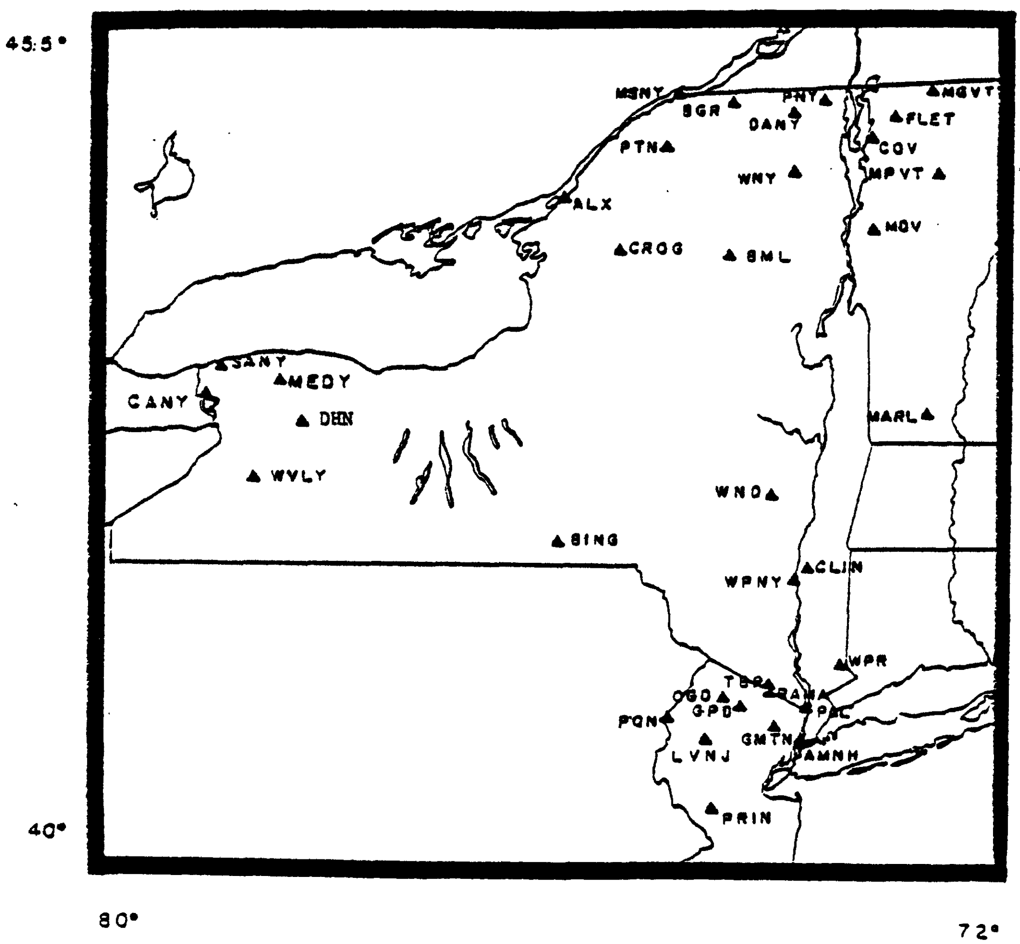

Figure 1: Distribution of short period seismic stations operated by Lamont-Doherty Geological Observatory in New York State and adjacent areas.

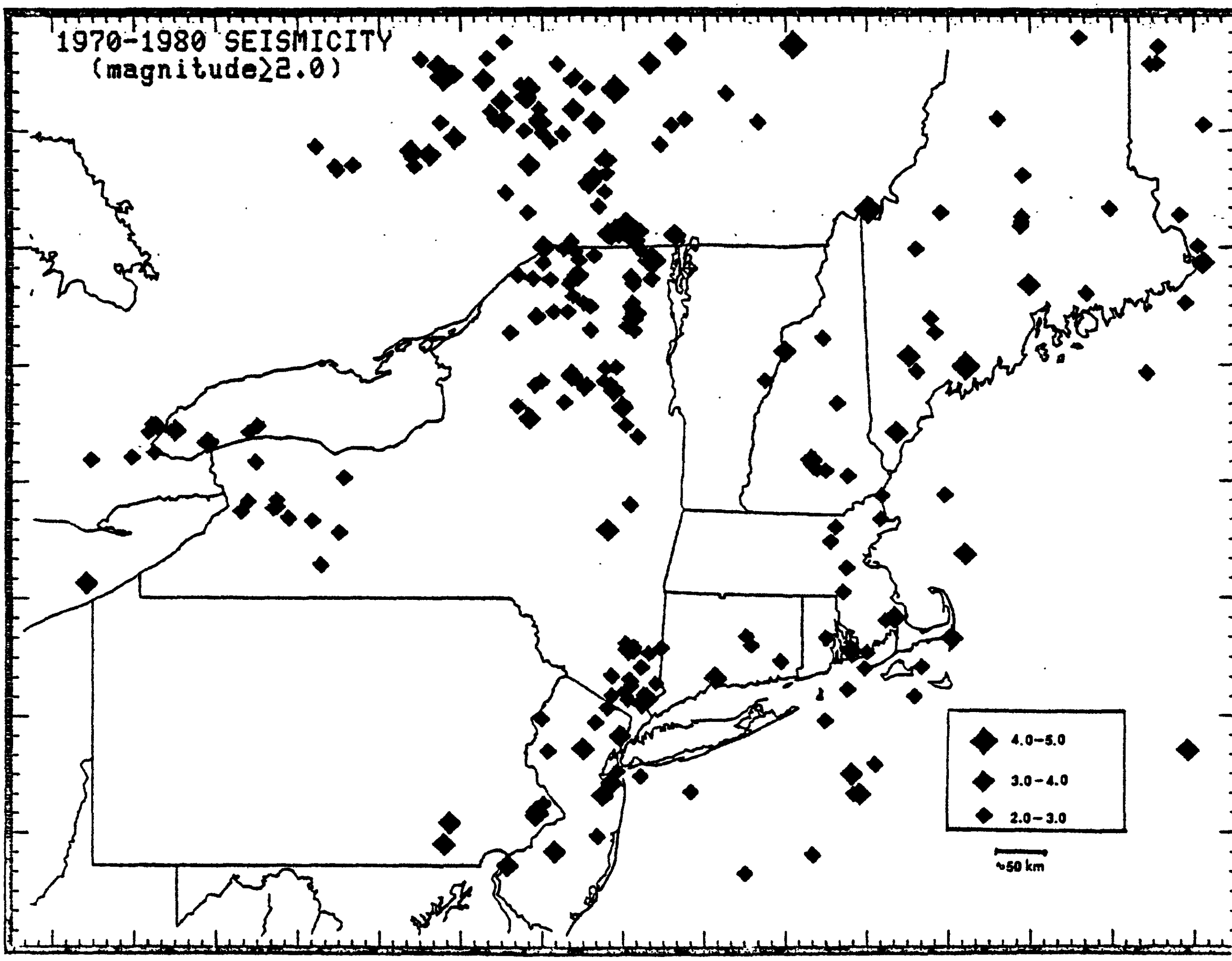

Figure 2: Distribution of earthquakes ($m_b > 2$) recorded by the Lamont-Doherty network from its inception in 1970 through 1980.

known geologic faults, the state of stress, and the crustal and upper mantle velocity structure in the northeastern United States and adjacent Canada. Since the inception of the network in 1970 over 900 local earthquakes ($1 \leq m_b \leq 5$) have been recorded and focal mechanism solutions for about 25 events have been determined. The results of studies of the network data are helping to enhance our knowledge of seismic phenomena and earthquake hazard in the northeast.

RESULTS

Earthquake Activity in New York State and Adjacent Areas: 1979-1980

In this section we discuss the distribution of earthquake activity in New York State and adjacent areas from the beginning of 1979 through the end of 1980. During this period of time 131 local earthquakes, ranging in magnitude from 1 to 5, were recorded by our network, and three earthquakes occurred within the area covered by our network which were well enough recorded that their focal mechanisms could be contstrained by P-wave first motions. These focal mechanisms will be described in the next section of this report.

Figure 2 shows the distribution of earthquakes ($m_b \geq 2$) recorded by our network from its inception in 1970 through 1980. In this figure we chose the magnitude threshold of $m_b = 2$ so as to reduce the bias introduced by non-uniform coverage in space and time. The major features of interest in Figure 2 are:

1) A NNW trending zone of seismicity extending from northern New York to western Quebec.

2) A northeasterly trending belt of seismic activity extending from New Jersey into Connecticut.

3) Concentrations of seismicity in western New York and western Lake Ontario.

4) Relative absence of activity in the central part of New York State, Vermont, and western Massachusetts.

A comparison of the instrumentally recorded seismicity with the historical earthquake record for this region (see Semi-Annual Technical Report) reveals that these features are relatively stationary. Those areas of the northeast that have had little or no seismicity historically are relatively aseismic today, whereas the historically active areas are also active today.

All of the earthquakes recorded during 1979 are shown in Figure 3. For most areas our recording threshold is now about magnitude 1.5. We see in this figure that significant activity has been recorded in northern New York and western Quebec, and also in the New York City region. During 1979 very little activity was recorded in western New York.

Figure 4 shows some more recent events recorded during 1980. A comparison of Figures 3 and 4 shows that, in general, 1980 was a much more active year than 1979. Whereas in 1979 only 48 events were recorded, 83 events were recorded in 1980. Since we had a change in both record analyst and network supervisor personnel in the middle of 1979, we carefully analyzed our bulletins and seismic records for this period in an effort to ascertain if this low level of seismic activity for 1979 is real. To date we have not discovered any difference in reporting of events recorded, and we conclude that the catalogue of earthquakes is complete for both 1979 and 1980.

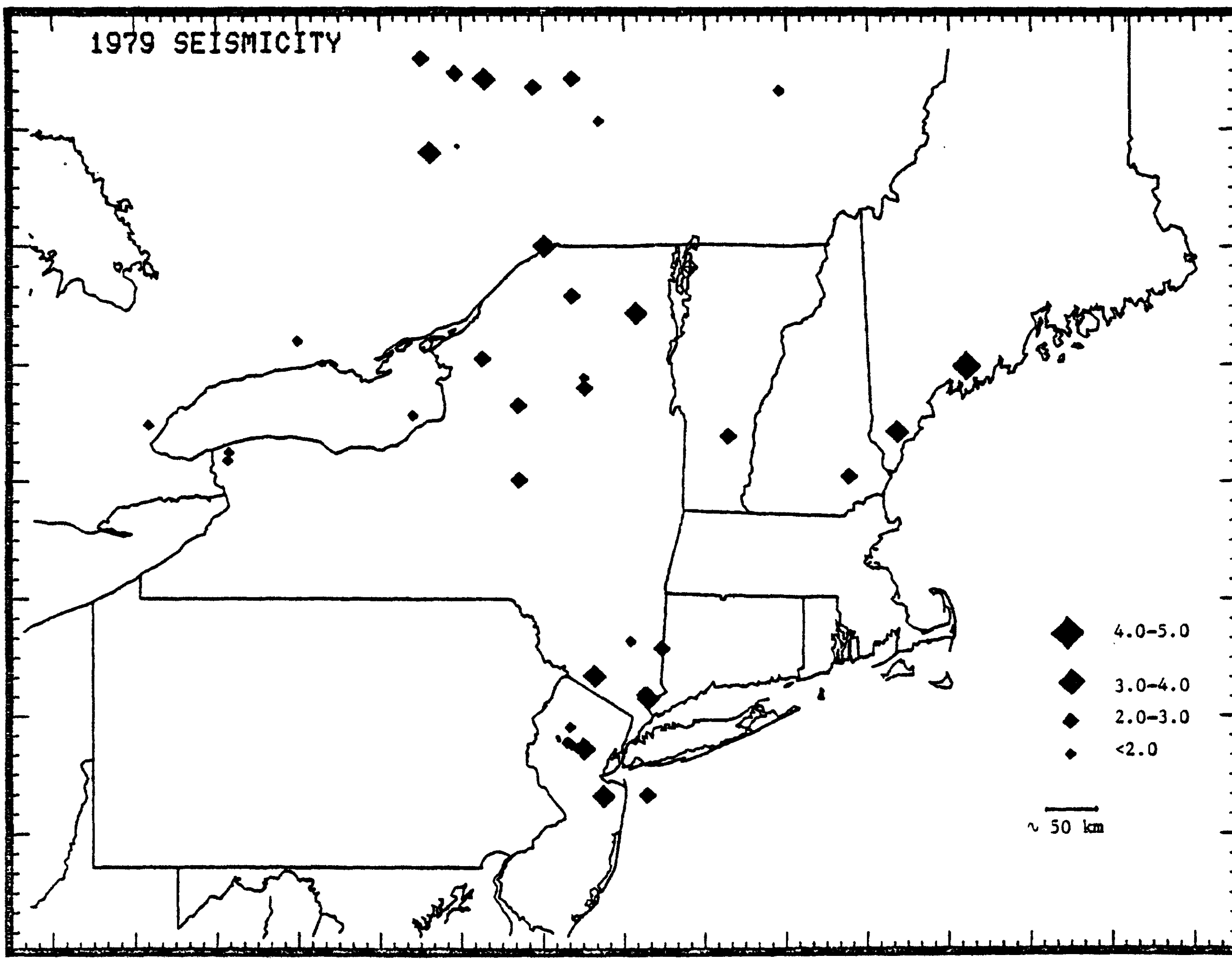

Figure 3: All earthquakes recorded by the Lamont-Doherty network during 1979.

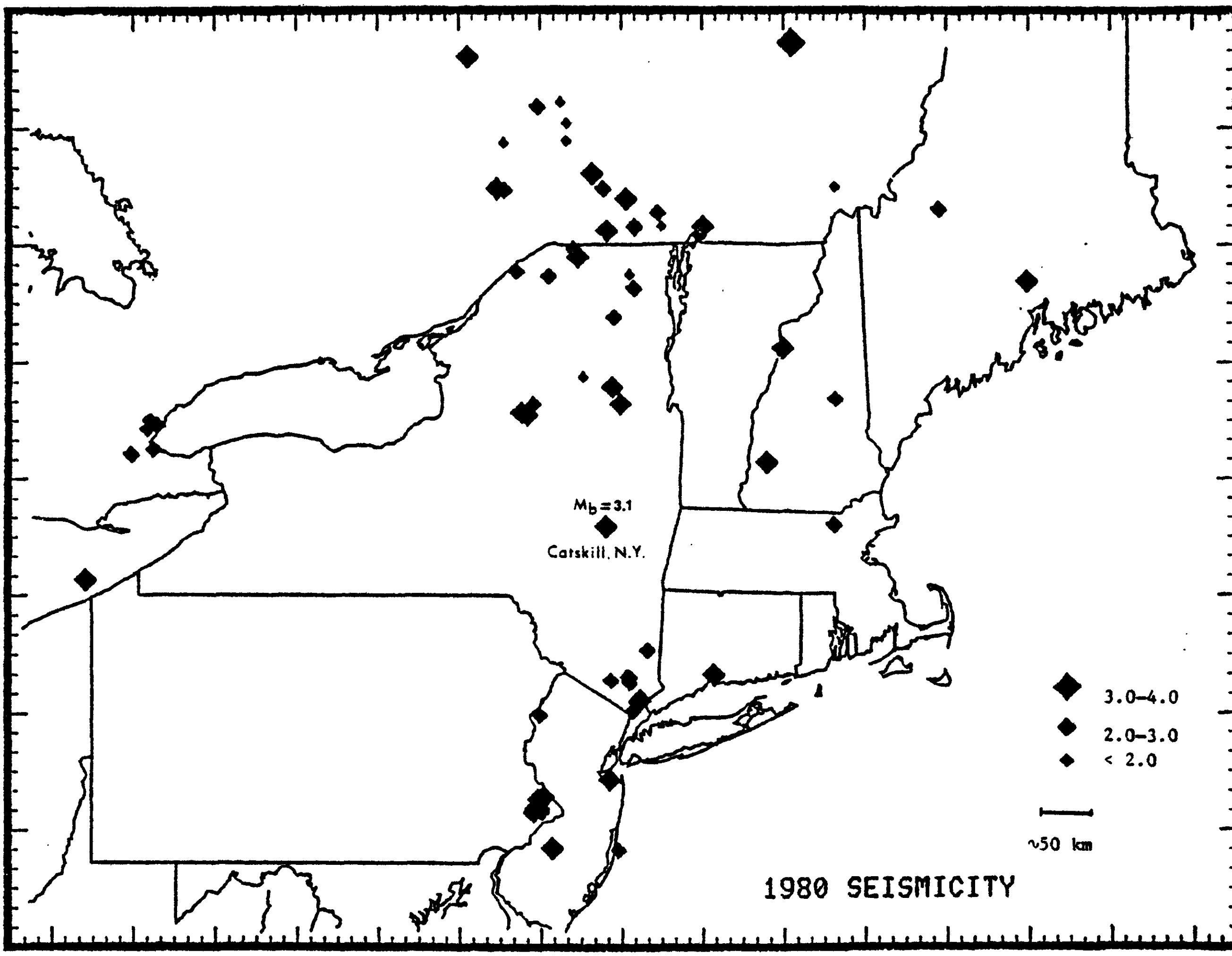

Figure 4: All earthquakes recorded by the Lamont-Doherty network during 1980.

During 1980 the northern New York - western Quebec region and the greater New York City region both show activity. Several events were recorded near western Lake Ontario, and a significant sized event of m_b = 3.1 was recorded near Catskill, New York in an area which shows relatively low activity over the past decade. Five earthquakes were recorded north of Philadelphia, Pennslyvania; these events were discussed in the Semi-Annual Technical report.

Focal Mechanisms of Three Recent Earthquakes in New York State

On June 6, 1980 an event of m_b = 3.8 was located by our network near Boonville, New York close to the contact between the Adirondacks and the Paleozoic structures of western New York (Figure 6). We have determined the focal mechanism (Figure 5) of this event using P-wave first motion data from our network and other nearby networks. Note that in some parts of the focal hemisphere compressions and dilatations straddle the nodal plane. We attribute this scatter to be due to errors in location, depth, and assumed earth structure which we will discuss below.

Figure 6 shows the solution for the Boonville earthquake along with the results of Yang and Aggarwal (1980) for other events in the Adirondack region. Note that the agreement is quite good, and in general events show thrusting on NNW or NW striking planes. In contrast, the predominant trend of mapped or inferred faults in northern New York is northeasterly and only a small number of NW trending faults have been mapped. Yang and Aggarwal (1980) have been able, in a few cases, to associate NW trending mapped faults with earthquakes such as the 1975 Raquette Lake events.

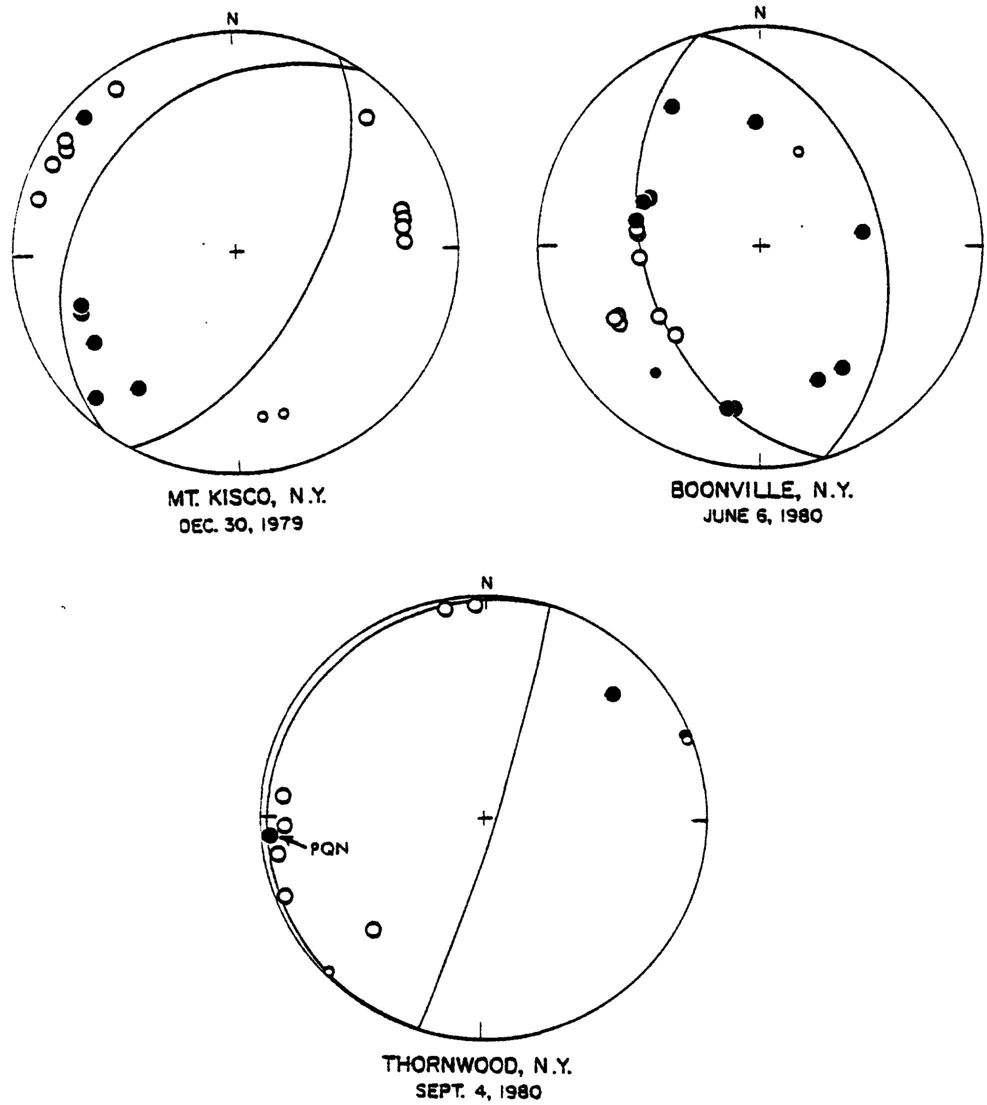

Figure 5: Focal mechanism solutions (upper hemisphere) for three recent earthquakes which occurred within the area covered by the Lamont-Doherty network. Open circles represent dilatations and closed circles represent compressions.

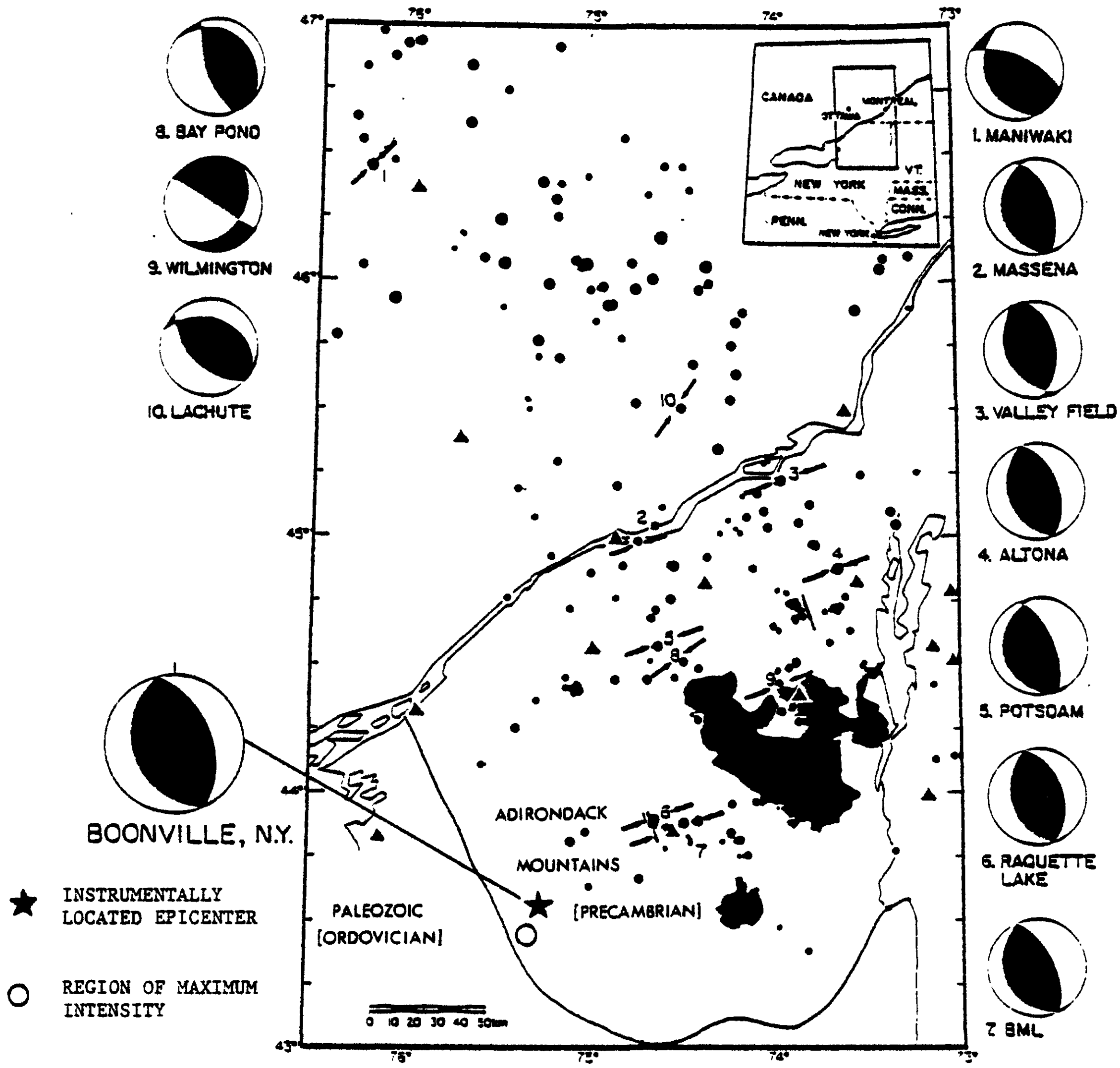

Figure 6: Seismicity recorded by the Lamont-Doherty network and focal mechanism solutions (upper hemisphere) for the northern New York - western Quebec region.

The location we obtained for the Boonville earthquake is shown by the star in Figure 6, and the depth we obtained was 1 km. We associate somewhat larger uncertainties with this hypocenter than usual, however, since the earthquake occurred near a boundary between two geologic structures. Also, the nearest station was about 50 km from the epicentral solution. In obtaining the epicentral solution shown in Figure 6 we used two different earth models. Our northern New York model was used for stations to the east, and our western New York model was used for stations to the west. The maximum intensities were, however. reported to the SW of the instrumentally located epicenter (see Figures 6 and 7) in a region closer to the contact between the Adirondacks and the Paleozoic structures. We note that this contact strikes nearly parallel to the strike of the nodal planes of the Boonville earthquake, and we are currently investigating the relationship between this contact and the site of the earthquake. We are also considering the possibility that the Boonville earthquake may be related to NW trending faults within the Aidrondacks which are not readily visible on the surface.

On December 30, 1979 an earthquake of $m_b = 3.0$ was recorded near Mt. Kisco, New York within the Manhattan Prong. The focal mechanism for this event is shown in Figure 5. The solution we obtained is predominantly thrust faulting with NE striking nodal planes. We obtained a depth of 4 km for this event.

On September 4, 1980 another earthquake ($m_b = 3.2$) was recorded in the Manhattan Prong. This event was located near Thornwood, New York (see Figure 8). Because of the location of this event relative to station distribution the solution is not as well constrained as the solution for the Mt. Kisco earthquake. The P-wave data for the Thornwood event is shown

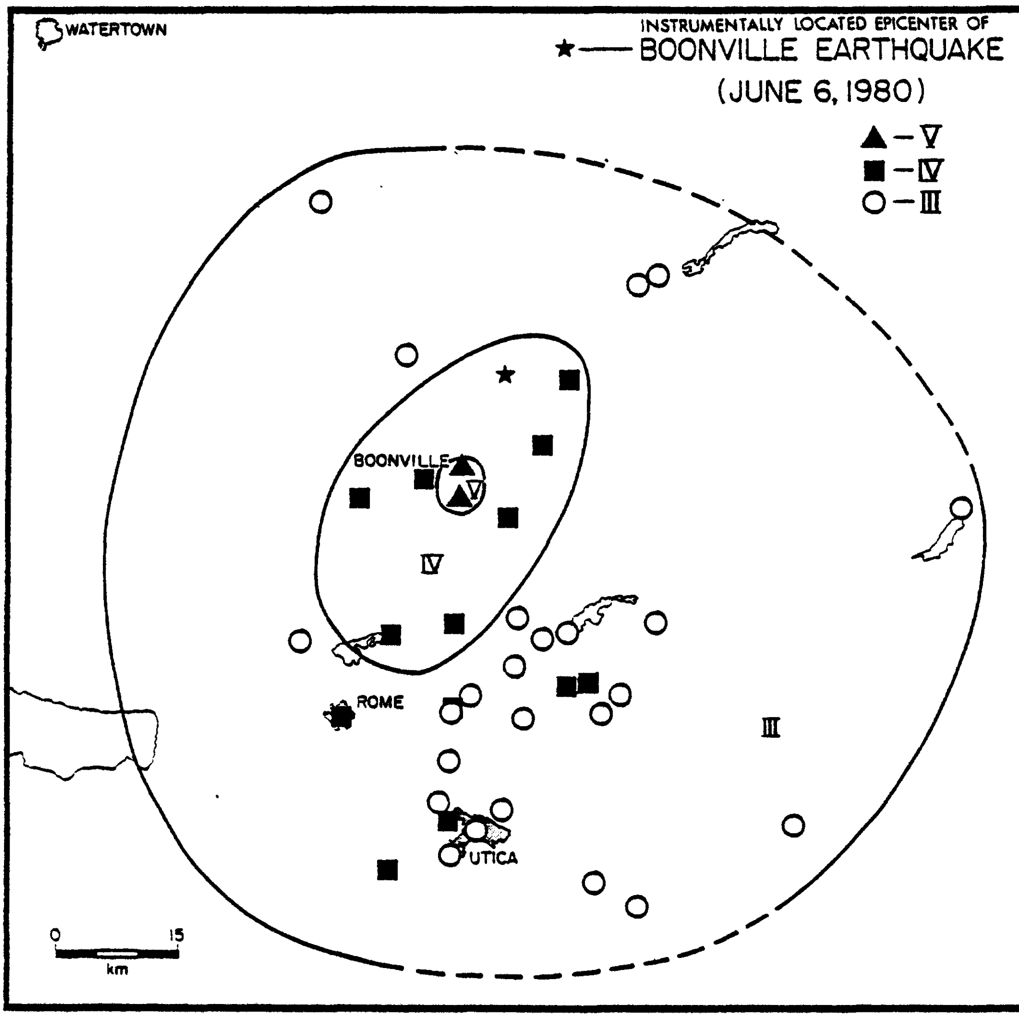

Figure 7: Modified Mercalli intensity survey for the Boonville, New York earthquake.

in Figure 5. It would be tempting to draw a thrusting mechanism with NE trending nodal planes for this event to force a consistency with the solution obtained for the Mt. Kisco earthquake. The compressional P-wave reading at station PQN (Figure 5) was, however, very clear, with well determined station polarity, and we could not discard this data point. We suspect that further analysis of uncertainties in earth structure and hypocentral location may show that this is a refracted arrival which should really be plotted at a different position on the focal hemisphere. For the present, however, we maintain the result as shown in Figure 5. The NE trending fault plane shown in Figure 5 for this event is not determined by the P-wave data but was assumed due to the northeast trend of the seismicity, other focal mechanism fault planes, and the structural trends in this region (see Figure 8). We emphasize that this plane is not well constrained by the data shown here.

Figure 8 shows the solutions for the Mt. Kisco and Thornwood earthquakes along with the focal mechanism results of Yang and Aggarwal (1980) for the New York City region. Also shown are the locations of other earthquakes located by the Lamont-Doherty network in this region. Aggarwal and Sykes (1978) have shown that many of the earthquakes in Figure 8 are spatially related to the various mapped branches of the Ramapo fault system. Significant earthquake activity, however, has been recorded within the Manhattan Prong to the southeast of the northern branches of the Ramapo fault system. Note that the solution obtained for Mt. Kisco is consistent with the Yang and Aggarwal (1980) results for events 16 and 17 within the Manhattan Prong and for many other events to the west. Also note in Figure 8 the lineation of seismicity parallel to both a magnetic lineation inferred from the data of Barosh et al. (1974) and the strikes of

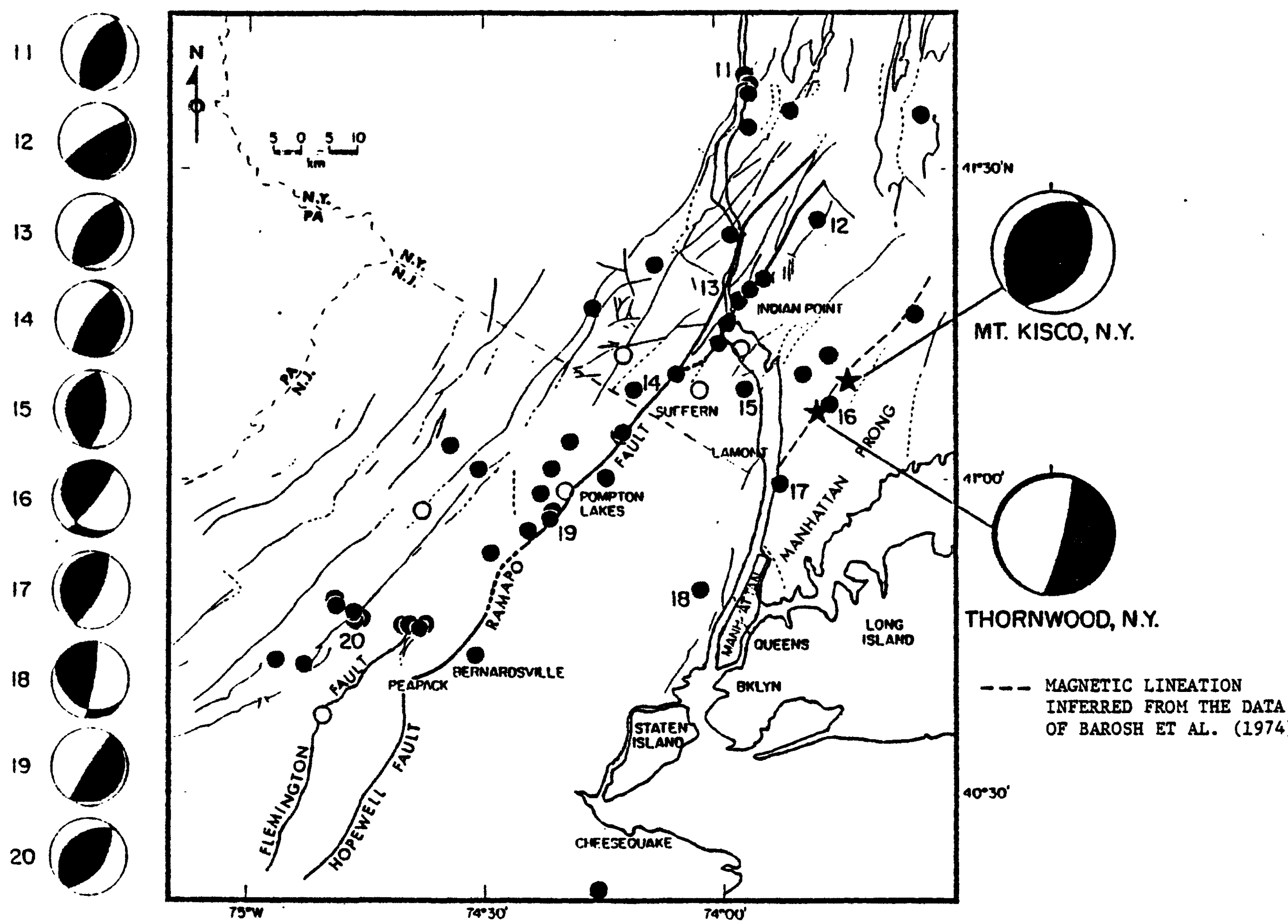

Figure 8: Well located earthquakes in the greater New York City area showing the Ramapo fault system and other related faults. Open circles are earthquakes occurring between 1957 and 1974. Closed circles are events occurring between 1974 and 1980. The focal mechanisms of events 11 through 20 are from Yang and Aggarwal (1980), and those for the Mt. Kisco and Thornwood events are from Kafka et al. (1980).

the NE trending fault planes of the Mt. Kisco earthquake and events 16 and 17 of Yang and Aggarwal (1980). This trend also coincides with a contact between the Fordham gneiss and the Inwood marble units shown on the structural maps of Ratcliffe (1980). We are presently investigating the relationship of this lineation to earthquake activity within the Manhattan Prong.

The results described above have been presented at a recent Eastern Section meeting of the Seismological Society of America (October 27-30, 1980; Pennsylvania State University), and a paper describing these and other recent results generated by the network data is in preparation.

MEETING OF NEUSSN OPERATORS AND SPONSORS

On Monday, October 27, 1980 we ran a one day meeting of all network operators and sponsors of the Northeast United States Seismic Network (NEUSSN). The meeting was held at Pennsylvania State University, on the day before the meeting of the Eastern Section of the Seismological Society of America. The participants primarily discussed: (1) discrimination between quarry blasts and earthquakes; (2) calculation of local magnitudes; (3) interpretation of Modified Mercalli intensity surveys; and (4) development of new methods of determining focal depths. The communication among the network operators and sponsors was very informative, and a decision was made to hold similar meetings approximately every six months. The minutes of the October 1980 meeting are attached to this report (see Appendix).

PUBLICATIONS AND REPORTS

Aggarwal, Y.P., 1980, Scaling Laws for Global Plate Motions: Implications for Plate Dynamics, submitted to Nature.

Bischke, R.E., A.L. Kafka, and E. Schlesinger-Miller, 1980, The Abington, Pennsylvania Earthquake Sequence of March 1980 [Abst.], Eastern Section Seismol. Soc. Am., October 28-30, 1980.

Kafka, A.L., E. Schlesinger-Miller, and L.R. Sykes, 1980, Recent Seismic Activity in the New York State Region [Abst.], Eastern Section Seismol. Soc. Am., October 28-30, 1980.

Kafka, A.L., E. Schlesinger-Miller, and L.R. sykes, Earthquake activity in New York State and adjacent areas; 1979-1980, in preparation.

Schlesinger-Miller, E., A. L. Kafka, G. Porro, and J. Krause, 1980, Attenuation of Modified Mercalli Intensity with Distance for New York State and Adjacent Areas [Abst.], Eastern Section Seismol. Soc. Am., October 28-30, 1980.

Schlesinger-Miller, E., Regional Seismicity Bulletin (1979) of the Lamont-Doherty Network: Lamont-Doherty Geological Observatory Publication.

Schlesinger-Miller, E., Quarterly Report (January-March 1980) of the Lamont-Doherty Network: Lamont-Doherty Geological Observatory Publication.

Yang, J.P., and Y.P. Aggarwal, 1980, Seismotectonics of Northeastern U.S. and Adjacent Canada, submitted to J. Geophys. Res.

Yang, J.P., and Y.P. Aggarwal, 1980, Crustal Stress in Eastern and Arctic North America: Observations and Causal Mechanism, in preparation.

APPENDIX

Meeting of Northeast U.S. Seismic Network (NEUSSN) Operators and Sponsors

Monday — 27 October 1980
Pennsylvania State University

Minutes

Morning Session: 9:00 A.M. -- 12:00 Noon

(1) Discrimination between earthquakes and quarry blasts was discussed. The simplest approach is to accumulate records of known quarry blasts as well as a list of active quarries in the region of interest. Whenever an event is located near a quarry the observed wave form is compared to the records of known blasts and, if necessary, the quarry operators are contacted. Problems are encountered when events occur in areas where lists of quarries are unavailable or incomplete, and when new quarries are established or old quarries are reactivated. It was suggested that a more rigorous wave form and/or spectral analysis method should be developed, and some discussion followed about the progress of various network operators in this direction.

Wave form and spectral analysis using digital data was discussed for both earthquake and quarry blast sources. Jay Pulli (MIT) presented several slides of digital data recorded by the MIT network. He suggested that the presence of surface waves may be useful in determining depths of seismic events and the shape of S wave spectra may help in discriminating between quarry blasts and earthquakes.

(2) Each of the network operators presented their method of calculating magnitudes. The most commonly used methods are (1) measuring the Lg wave amplitudes to calculate Nuttli M_{bLg} magnitudes, and (2) determining magnitudes from measurement of coda length. Some discussion followed about the proper use of both types of scales. Many participants agreed that a unified magnitude scale should be developed that is applicable to all of the northeast networks.

Afternoon Session: 1:30 P.M. -- 5:00 P.M.

(1) A suggestion was made by Nick Ratcliffe (USGS) that a more serious effort should be made to incorporate geological data and expertise into the analysis of seismic problems.

(2) Modified Mercalli intensity surveys were discussed. Alan Kafka and Ellyn Schlesinger-Miller (LDGO) distributed and discussed their questionnaire. They emphasized the need for simple multiple choice questions to help make the assigning of intensity values more routine and to make it easier for respondents to answer. Also, in their

experience newspapers are more likely to publish a short and concise questionnaire than a long one. They suggested that "not felt" data are extremely important in defining the extent of the felt area and that respondents should be encouraged to fill out the form even if the only information on it was that they didn't feel the earthquake.

It was suggested that we use the same questionnaire which the USGS routinely distributes to postmasters after an earthquake. Some participants, however, were cautious about using these forms because they were designed for larger earthquakes than we commonly experience in the northeast. For example, in the case of northeastern earthquakes it is often important to distinguish between intensity III and intensity IV, and this should be addressed in the questionnaire.

Gary Nottis (NYSGS) gave a short discription of his research on intensity surveys for historical events. He emphasized the problem of distinguishing between tectonic earthquakes and cryoseisms.

A short discussion followed on the appropriateness of asking questions that relate to strange animal behavior. It was generally agreed that this should not be done because (1) this is an area of investigation beyond the scope of our research and (2) if people wish to write something about animal behavior they can write it as an answer to a general question asking for additional comments.

(3) Azimuthal station coverage for events between subnetworks was discussed. It was generally agreed that for such events cooperation between network operators is very important for gathering first motion data, calculating magnitudes, and carrying out aftershock studies. Paul Pomeroy (Rondout Assoc.) said that it was very important that network operators agree about who is responsible for a given event. It was decided that the names and phone numbers of network operators should be published and kept up to date in the NEUSSN bulletins.

(4) Methods of determining focal depths were discussed. Paul Pomeroy stated that it is very important to the USGS and the NRC that we accurately determine the focal depth distribution of earthquakes in the northeast U.S. At present, accurate focal depth determination is possible only for those events which fortuitously occur close to a station or for those events recorded by aftershock studies. Ellyn Schlesinger-Miller stated that depths are well constrained for certain areas within New York State where station density is high, such as the Blue Mountain Lake and Indian Point regions. The large majority of the depths recorded in bulletins are the results of a best fit to the P-wave and S-wave data observed at permanent network stations. Most network operators agree that it is difficult to assess how meaningful these depths are. It was, therefore, decided that research on the use of additional body wave phases and surface waves for depth determination should be pursued. These studies would, of course, require digital data in order to study wave forms and spectra.

(5) At 4:00 P.M. the general discussion of NEUSSN research problems ended, and Paul Pomeroy led a one hour discussion on technical and

funding problems. A major problem from both a technical and funding point of view is that the cost of TELPAK lines will probably double or triple in the near future. This will make it increasingly difficult to continue using the present number of TELPAK lines. Operators should seriously review the present configuration of any telephone lines that are being used, and attempt to make the most efficient use of TELPAK lines as possible. An effort should be made to use radio telemetry as often as possible. The possibility of recording locally at each station or group of stations and triggering on events was discussed.

Paul Pomeroy emphasized that the NRC and the USGS future funding for networks will probably at best remain at the present level. He restated that network operators should seriously investigate methods of determining the depth distribution of earthquakes.