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RESEARCH IN SEISMOLOGY

PROGRESS REPORT IN EARTHQUAKE MECHANISM, MAGNITUDE, SPECTRAL PROPERTIES, AND MODEL STUDIES.

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ABSTRACT

The research may be categorized as work on: earthquake focal mechanisms, earthquake and explosion magnitude and energy determinations, spectral properties of earthquakes and explosions, model studies of strain release and coupling and continued study of regional seismicity. The principal results reported are: (1) an improved technique for determining the best-fitting focal mechanism relation by combining P-amplitude and S-wave polarization data has been developed; (2) a technique for determining the fault plane solution using P-wave amplitude data has been developed; (3) the concept of a dominant focal mechanism controlled by plate tectonics for a given seismically active region has been tested and a method for sorting events that do not fit that mechanism developed; (4) the energy in the long-period part of the spectrum of explosion-generated P-waves has been studied, together with the inelastic attenuation of this energy; (5) a method for determining the distance from the source at which a specified level of strain occurs from observed P-wave amplitudes at large distances has been developed; (6) P-wave and S-wave spectra of moderate to small earthquakes recorded at short distances have been interpreted in terms of fault length and stress drop; (7) the magnitude-frequency relation and spatial distribution for moderate to small earthquakes in the New Madrid seismic zone has been determined for an interval of about one year; (8) model studies of explosions in prestressed media and of the effect of the medium around the source have been completed with fair success.

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Summary of Research

The research completed during the year covered by this report may be broadly categorized as work on: earthquake focal mechanisms, earthquake and explosion magnitude and energy determinations, spectral properties of earthquakes and explosions, model studies of strain release and coupling and continued study of regional seismicity. Although this classification of the work is convenient for purposes of organizing this discussion of the results, there is considerable overlap between the areas. For example, the results of focal mechanism studies have been incorporated in investigations of magnitude determinations, the spectral properties are studied in relation to focal parameters, the regional seismicity studies furnish data for the spectral studies, etc.

The principal results can be briefly summarized as follows:

(1) an improved technique for determining the best-fitting focal mechanism relation by combining P-amplitude and S-wave polarization data has been developed;

(2) a technique for determining the fault plane solution using P-wave amplitude data has been developed;

(3) the concept of a dominant focal mechanism controlled by plate tectonics for a given seismically active region has been tested and a method for sorting events that do not fit that mechanism developed;

(4) the energy in the long-period part of the spectrum of explosion-generated P-waves has been studied, together with the inelastic attenuation of this energy;

(5) a method for determining the distance from the source at which a specified level of strain occurs from observed P-wave amplitudes at large distances has been developed;

(6) P-wave and S-wave spectra of moderate to small earthquakes recorded at short distances have been interpreted in terms of fault length and stress drop;

(7) the magnitude-frequency relation and spatial distribution for moderate to small earthquakes in the New Madrid seismic zone has been determined for an interval of about one year;

(8) model studies of explosions in prestreased media and of the effect of the medium around the source have been completed with fair success.

The results are here summarized in the form of brief digests. In most cases, the results are fully developed in papers already published, accepted for publication, or in preparation for publication (see Section 6).

Section 1.

Focal Mechanism Studies

W. Stauder, D. Wagner, L. Mualchin

Focal mechanism studies have been conducted in three areas: the Aleutian Islands, the Kurile Islands, and the Ecuador-Peru region of South America.

Fault Motion and Spatially Bounded Character of Earthquakes in Amchitka Pass and the Delarof Islands. During the period May 1969 to March 1970 seven moderate earthquakes occurred in the Delarof-Andreanof Islands region. The focal mechanisms of these earthquakes correspond to the motion expected on the basis of plate tectonics. Of more particular significance, the motion in one of these shocks located at intermediate depth in the Benioff zone indicates horizontal tension parallel to the plate, corresponding to lateral extension as the plate descends under an arcuate structure convex to the plate motion. The spatial and temporal relation of these earthquakes and of their aftershock sequences to the overall activity of the arc, and particularly to the seismicity of the Rat Islands during this period, supports the hypothesis that the Aleutian Islands are active by independent blocks, and that the boundaries of these blocks are permanent features.

Larger Earthquakes of the Kurile Islands, 1962-1968. The focal mechanisms of 45 earthquakes occurring in the Kurile Islands during the years 1962-1968 have been determined. In the great majority of these earthquakes one of the nodal planes is well determined on the basis of the P and S wave data. Its strike is northeast, and the dip is 55° to 80° southeast. The second plane is less well determined, but is constrained to dip moderately to the north, trending east-west. Only two of the earthquakes examined occurred beneath the Kurile Trench. The mechanism in these cases is apparently reversed faulting, rather than tensional as in the Rat Islands. Other features are similar to those observed in earthquakes of the Aleutian Islands and support the hypothesis of plate tectonics. In four earthquakes, whose foci are distributed at increasing depth along an east-west line coinciding with the boundary between the Kurile Islands seismic zone and the Honshu-Hokkaido zone, one nodal plane is near vertical and aligned along the line of epicenters. The motion is interpreted as hinge faulting along the zone of flexure between two seismic zones in which the dip of the descending plate differs by some 30°. Application of

P-wave stationary phase approximation by equalization procedures enhances the quality of the mechanism in selected cases and permits determination of a revised magnitude and of earthquake moment.

Statistical Decision Theory Applied to Focal Mechanisms of Peruvian Earthquakes. First motion P-amplitudes and S-polarization angles have been measured from long-period WWSSN records for eighteen Peruvian earthquakes with body-wave magnitudes in the range 5.8 - 7.5. Fault plane solutions which simultaneously satisfy the P and S data were determined by maximizing a linear cost function. The results show a vertical pressure axis for five deep events, and a tension axis in the plane of the slab for three intermediate depth inland events. Coastal earthquakes indicate two events under the trench with horizontal tension axes, three steeply dipping planes, and one event dipping slightly (20°) under the continent. Four shallow inland events do not appear related to the plate tectonics.

These studies have made use of several new techniques in focal mechanism investigation: 1) a stationary phase approximation procedure was applied in reducing P-amplitude data to the source, allowing a determination of seismic moment in conjunction with the determination of other focal parameters, 2) a determination of the focal mechanism by a least square best fit of the residuals of P amplitudes reduced to focal spheres, 3) a cost-function approach, establishing a statistical base for a focal mechanism solution simultaneously best satisfying two or more kinds of data, e.g. P amplitude data and S wave polarization data. Anomalies in the mechanism-corrected P amplitude residuals provide evidence of inhomogeneity in the source region (the effect of subduction of oceanic crust), and the space-time seismicity relationships indicate that linear seismic zones are active by segments in a repeating fashion so that an event, e.g., in the Rat Islands, is not likely to trigger or influence activity in the neighboring Delarof block.

Section 2.

Amplitude, Magnitude, and Energy

2.1 The Amplitude of Teleseismic P Waves.

Otto Nuttli

The objectives of this research were: 1) to improve, if possible, the calibration ($\overline{Q}$ - Δ) function of Gutenberg and Richter (1956), which is used for the calculation of body-wave magnitudes and 2) to utilize teleseismic P-wave amplitude data in a search for regions of abnormal velocity variation in the lower mantle.

Data used for this study were obtained from the long-period seismograms of the WWSS and Canadian networks for the Oct. 27, 1966 and Oct. 14, 1970 nuclear explosions at Novaya Zemlya, MILROW on Amchitka Island and the NTS events GREELEY, BOXCAR and HANDLEY. Additional long-period amplitude data for two Aleutian Islands earthquakes and short-period data for the Oct. 27, 1966 Novaya Zemlya event also were obtained.

All amplitude data were equalized to an event of body-wave magnitude 6.30. The data were averaged over 2.5° intervals of epicentral distance. From them a trial $\overline{Q}$ - Δ curve was constructed, which was perturbed several times until no further reduction in standard deviation of calculated magnitude could be obtained. Finally, the resultant calibration function was modified so that travel times calculated from the amplitude-distance relation closely conform to the Herrin et al (1968) P-wave travel times.

The newly derived amplitude-distance relation agrees closely with that obtained theoretically by Duda (1971) and empirically by Willey, Cleary and Marshall (1970). It differs substantially from that of Gutenberg and Richter (1956) at epicentral distances of about 35° to 45° and 60° to 70°, and suggests that magnitudes determined using the Gutenberg-Richter tables are underestimated by about 0.3 units at distances of 35° to 45° and overestimated by about 0.2 units at distances of 60° to 70°.

For the six explosions and two earthquakes considered in this study, the magnitudes determined using the new calibration function had a smaller standard deviation than those determined from the Gutenberg-Richter function. The

difference in magnitudes obtained using the two different functions was small, never exceeding 0.05 units for any event, because for all eight events there was available a large amount of data distributed over a wide range of epicentral distances. However, if body-wave magnitudes are determined using the Gutenberg-Richter function for data from only a few points, such as LASA and NORSAR, they may be in error by as much as $\pm$ 0.3 magnitude units.

Other factors can influence or cause errors in body-wave magnitude determinations. For explosions they include anomalous geologic structure at the source or at the seismograph station. For earthquakes there is in addition the effect of the unequal azimuthal radiation of energy. Both the long- and short-period P-wave amplitudes from MILROW showed an effect of the Aleutian plate, which caused in general a reduction of P-wave amplitudes at European, Caribbean and eastern United States stations. A similar phenomenon is seen for P-wave amplitudes from earthquakes in the Aleutian Islands, but not for those in the Aleutian Trench.

A comparison of the short- and long-period amplitude data of the 1966 Novaya Zemlya explosion leads to the conclusion that anelastic attenuation is greater in the upper than in the lower mantle, although the overall effect of anelastic attenuation on the amplitude of P waves with period of 1 second or greater is much less than that of geometric spreading. Therefore the $\bar{Q}$ - Δ function derived in this study should be applicable to P waves recorded by 1 second period seismographs as well as by longer period seismographs.

The amplitude data hint at the existence of second-order velocity discontinuities at depths of about 1400 and 2300 kilometers. They confirm the existence of a first-order velocity discontinuity at a depth of about 700 kilometers.

A more complete discussion of these results, as well as tabulated values of the calibration function, is to be found in the paper by Nuttli (1972).

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2.2 A Seismic Discriminant Based on Focal Mechanism.

Atiq A. Syed, Carl Kisslinger and Otto W. Nuttli

The hypothesis that earthquakes in highly seismic regions are controlled by motions related to sea-floor spreading provides a basis for rapidly sorting out anomalous events in such regions. These events might be earthquakes for which the focal mechanism is different from that expected from the regional tectonics or they might be undergeound explosions. Obviously, focal-mechanism solutions for all events in a region would provide a means of selecting anomalous ones for further study, but this approach would require a great deal of time and is not considered practical for continuous, routine screening. A technique based on body-wave magnitude has been developed that makes possible the fast determination of whether the event fits the "normal" focal mechanism for the region, once the location is known and the P-wave amplitudes have been read.

The technique is based on the premise that a predominant focal mechanism exists for a given seismic region and that this mechanism can be predicted from plate tectonics. Syed and Nuttli (1971) tested this premise in detail for Kamchatka, the Aleutians and the mid-Atlantic Ocean, and found that it is possible to derive an average mechanism for any location within each seismic zone that fits most events within limits that can be specified statistically.

Once the predominant focal mechanism is known, the P-wave radiation pattern for that mechanism can be used to correct the recorded P amplitudes to give the amplitudes that would have been recorded from a spherically symmetric source with the same average amplitude over the focal sphere. The method was derived for improvement of magnitude determinations and has been applied for that purpose. However, if the corrections to the body-wave magnitudes for the predominant focal mechanism are applied to an event for which the mechanism is different, the magnitudes derived from the resulting corrected amplitudes will reveal the error, and the event is identified as not

fitting the regional tectonics.

The method was applied to both the long- and short-period P-wave amplitude data of the nuclear explosion MILROW, which occurred at Amchitka Island in the Aleutians on October 2, 1969. If the radiation pattern of MILROW were similar to that of typical earthquakes in the Aleutian Islands, then there should be one set of WWSSN stations (called A) for which the average m_b is at least 0.3 magnitude units greater than that of a second set (called B). The stations which belong to set A and to set B are listed in Syed and Nuttli (1971). However, the amplitudes of P waves from MILROW result in m_b of set B being 0.32 units greater than m_b of set A for the long-period data, and 0.23 units greater for the short-period data. This is striking evidence that the P-wave radiation pattern of MILROW is unlike that of earthquakes in the same region, and that the magnitude-sorting procedure would have picked it out as an anomalous event. It should be noted that for earthquakes in this region the m_b determined from the stations of set A was 0.3 or more units greater than that determined from the stations of set B.

The discrimination method was applied also to a mid-Atlantic earthquake of August 3, 1963. It correctly sorted out the earthquake as not being of the tension type, associated with ridges, but rather of the transform-fault type. This confirms the findings of a previous focal-mechanism study of this earthquake by Sykes (1967).

The method is expected to be of value in routinely identifying earthquakes whose mechanisms do not correspond to those expected from plate tectonics. It also can be used to sort out explosions as anomalies, even for regions such as Kamchatka or the earthquake zone south of the Aleutian Trench axis, for which the fault-plane geometry results in compressional first motions at most or all available seismograph stations.

A more complete discussion of these finds, together with the numerical data, is to be found in the paper by Syed, Kisslinger, and Nuttli (1971).

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2.3 The Explosion Volume.

S. J. Duda and T. J. Bennett

In an earlier investigation performed under this contract (Duda, 1970) the volume of earthquakes was defined and numerically evaluated as function of magnitude. The earthquake volume is defined as the space surrounding the earthquake focus, within which the strains produced by the body waves during the earthquake exceeded a critical value.

The definition was applied to nuclear explosions and their volumes estimated. The necessary ray tracing technique was refined by taking into account not only the geometrical spreading of the wave front but also absorption of seismic energy along the ray path.

Eight nuclear explosions (see Table 1), well recorded at teleseismic distances, were analyzed, and the results compared with those from independent investigations. It was found that at the elastic-nonelastic boundary a strain of about 10^{-4} was reached during the explosion, the exact value depending on the anelasticity model chosen. Similarly, the stress at the elastic-nonelastic boundary was found to range from 4 to 32 bars, depending on the anelasticity model. The stress is in agreement with earlier findings reported by Kisslinger (1963).

Dynamic strains of the order of 10^{-7} were observed on strain meters at a distance of 29 km from the Benham explosion (Smith et al., 1969). Our computations, based on observations at teleseismic distances, predict a strain of 10^{-7} to prevail at a distance of 35 km. The two distances appear to be in good agreement, if the fact is taken into account that the distances were obtained in completely different ways.

A controversy exists in the literature as to the distance dependence of the strain generated by a seismic event. While theoretical considerations of a point-source in an elastic half-space lead to a strain-distance dependence proportional to R^{-3}, where R is measured from the center of the explosion to the point of observation (Midlin and Cheng, 1950), direct observations of a strain step amplitude indicate a distance dependence proportional to $R^{-3/2}$ (Wideman and Major, 1967).

Table 1

Event	Date	Depth Below Topographic Surface (km)	P-Wave Magnitude	Number of Stations Used in Estimating Magnitude	Radius of the Elastic-Nonelastic Boundary (km)	Radius Determined in Previous Studies Based on Sharpe's Model (km)
Benham	12/19/68	1.400	6.37 ± 0.24	8	(1.16)*	0.09 (Mueller (1969))
Boxcar	4/26/68	1.158	6.38 ± 0.20	9	(1.16)*	1.22 (Mueller (1969))
Commodore	5/20/67	0.744	5.81 ± 0.23	4	0.52	
Faultless	1/19/68	0.977	6.28 ± 0.30	15	1.00	
Greeley	12/20/66	1.216	6.40 ± 0.16	12	1.19	
Halfbeak	6/30/66	0.819	6.07 ± 0.18	5	0.87	
Jorum	9/16/69	1.167	6.33 ± 0.23	6	1.08	
Milrow	10/2/69	1.218	6.74 ± 0.21	12	1.95	1.25 (Wyss et al. (1970))

* These radii were assumed and set equal to the average of Mueller's (1969) estimations.

We found for the strain associated with a simple harmonic P-wave, radiated from a focus in a velocity heterogeneous anelastic Earth, the formula:

$$\epsilon(\Delta, f) = \Delta^{-D_h} \left[\frac{\pi C_h}{F(f)\ell c} \cdot 10^{m-\overline{Q}(80^\circ, h)} \right]$$

where Δ is the epicentral distance, C_h and D_h are quantities depending on the velocity model, $F(f)$ is a function of frequency, depending on the anelasticity model, ℓ is a geometric factor, c is the velocity of the P-wave at the level of the focus, m is the body wave magnitude of the event, and $\overline{Q}$ is the magnitude calibration function for the proper distance and focal depth. For a surface focus the strain is found to decrease with the -1.58 power of the distance, in agreement with the observational evidence referred to above.

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2.4 Recurrence Relation of Earthquakes.

S. J. Duda

The determination of the number of earthquakes in various magnitude classes, which have occurred in a certain region and time interval, appears to give presently the most promising means of prediction of future seismic activity. This probabilistic prediction of earthquakes originated with Gutenberg and Richter's (1954) work on the "Seismicity of the Earth," in which a recurrence relation of earthquakes was first proposed. The wide application of the method to various earthquake populations, and the further development of the method in the time since it was first published, makes it worthwhile to survey its applicability and specify the conditions under which it can yield correct results. Both the noncumulative and cumulative frequencies of earthquake populations are being studied as functions of the magnitude. If the noncumulative frequency is linearly related to the magnitude:

$$\log N(M_k) = A - B \cdot M_k \qquad M_1 \leq M_k \leq M_n \tag{1}$$

then the cumulative frequency is expressed by

$$\log N^*(M_k) = \log \sum_{i=k}^{n} N(M_i) = A + \log \sum_{i=k}^{n} 10^{-BM_i}) \ .$$

As seen, both frequencies cannot be simultaneously linear functions of magnitude. The question whether the noncumulative or the cumulative frequency of natural earthquakes is a linear function of magnitude has been investigated. From the population of 910 largest earthquakes which occurred between 1918 and 1964 worldwide (Duda, 1965) the indication is derived that natural earthquakes have noncumulative rather than cumulative frequencies linearly related to the magnitude (see Fig. 1a). Noncumulative frequency distributions constructed for a given population but with different magnitude increments ΔM, have slopes "B," independent of ΔM. This is proved to hold in general, and is shown in Fig. 1b. The B-values found for the 910 largest earthquakes and for different ΔM are about 1.1.

The B-value in (1) is found to depend on the number of earthquakes used for its determination. Consequently "B" does not provide in general information of tectonophysical significance, unless it is compensated for the population size.

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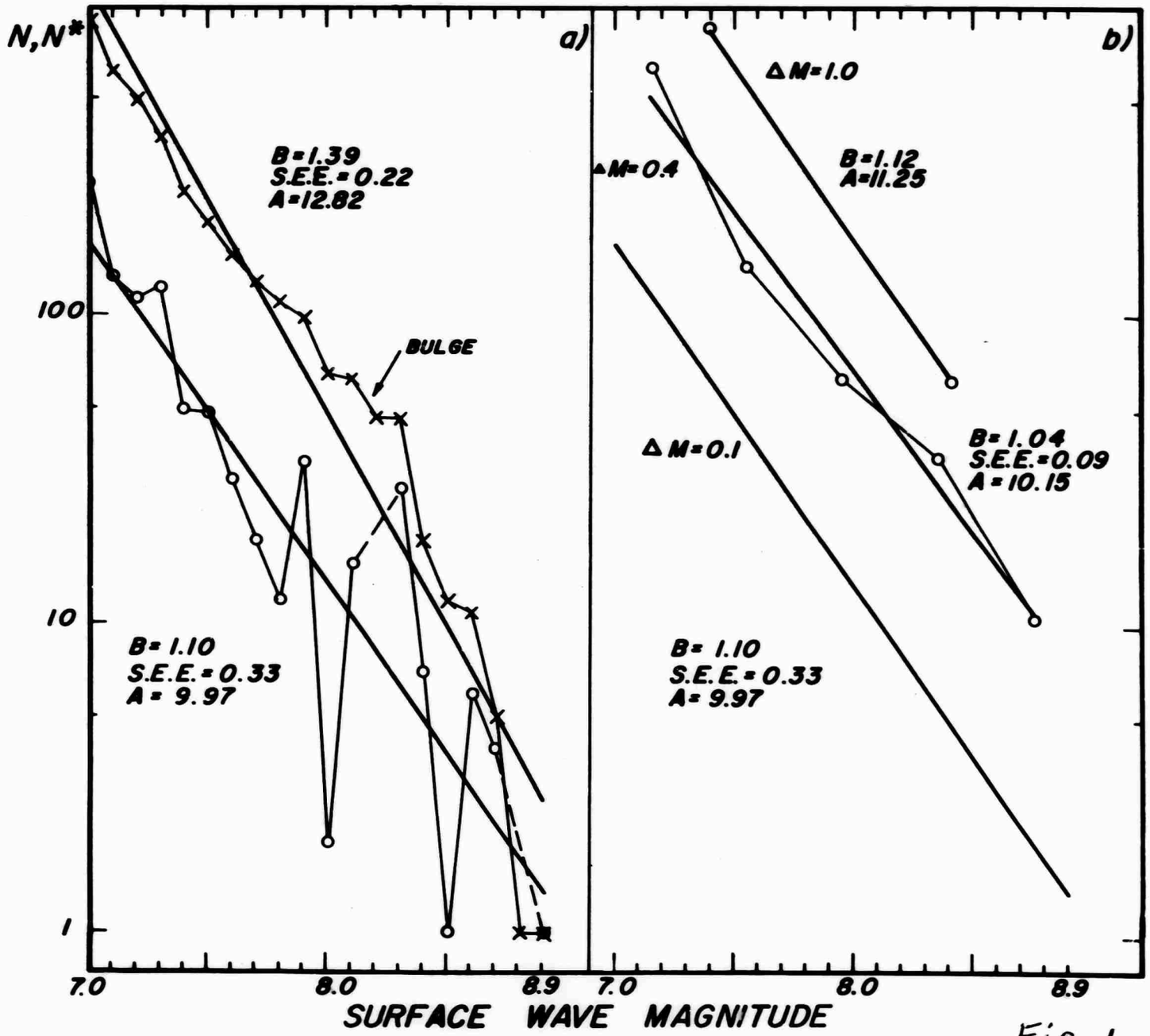
N,N*
a)
b)
B=1.39
S.E.E.=0.22
A=12.82
BULGE
B= 1.10
S.E.E.=0.33
A= 9.97
ΔM=1.0
ΔM=0.4
B=1.12
A=11.25
ΔM=0.1
B=1.04
S.E.E.=0.09
A=10.15
B= 1.10
S.E.E.=0.33
A= 9.97
100
10
1
7.0
8.0
8.9
7.0
8.0
8.9
SURFACE WAVE MAGNITUDE

Fig 1

It is concluded that the recurrence relation must be adjusted for the size of the population to which it is applied, in order for the constants to carry information unbiased by the population size. A recurrence relation of the form

$$\log N(M_k) = A - f(N_s) \cdot \overline{B} \cdot M$$

is proposed, where the function $f(N_s)$ compensates the slope of the recurrence relation for the number N_s of earthquakes actually used for the determination of A and B. $\overline{B}$ is the slope of the recurrence relation as would be obtained from a sufficiently large population, at which time $f(N_s)$, the compensating function, becomes equal to 1.0. $f(N_s)$ has been tabulated, and can also be approximated by $(1 - e^{-\alpha N_s})$. The best agreement with the tabular data is obtained for $\alpha = 0.02$. Even after compensation, the constants in the recurrence relation have an uncertainty, which decreases only with the increase of the population size.

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Section 3

Spectral Properties of Seismic Waves.

Carl Kisslinger and Rene Rodriguez

The difference in the spectral characteristics of seismic waves generated by explosions and earthquakes provide the foundation for some of the most promising criteria for distinguishing the two types of sources. The classical model of an explosion as a source of waves developed by J. A. Sharpe has been successful in explaining many features of explosion-generated seismic signals. Evidence is accumulating that the dislocation model of an earthquake, properly developed, can do as much for earthquakes. Recently Brune (1970) has produced a simple theory of S-wave spectra that represents an important step toward the calibration of fault length, seismic moment and stress drop from observed spectra in a simple way. As demonstrated by Wyss and Hanks and by our work, this method can also be applied to P-wave spectra.

This theory has been applied to earthquakes in two classes: mid-continental U.S. earthquakes recorded at short distances (up to 300 km) and deep earthquakes recorded at short distances. Three moderate events in the New Madrid zone, two of which (m_b 4.6 and 3.5) occurred in the same place 12 days apart (the smaller one first), were studied on the basis of data recorded at the Flat River (FRM) and St. Louis (SLM) observatories. The preliminary analysis yielded the following results for the length of the fault in each case:

m_b	Fault length from P-waves (km)	Fault length from S-waves (km)
4.6	2.1	2.2
3.9	1.2	1.8
3.5	1.1	1.2

The good agreement of the P- and S-wave results supports the use of the P-wave spectra in this way even though no rigorous theoretical basis for the procedure exists. The difference of one kilometer in fault length for a magnitude difference of one unit seems small, and could be explained as the result of a higher fractional stress drop for the larger earthquake.

The spectra from which the above results were obtained had not been corrected for inelastic attenuation. During the past few months, data on attenuation of S-waves has been accumulated. The frequency band involved is from 0.1 to 10 Hz, a band in which there has been little work done and in which the variation of Q (intrinsic absorption parameter) with frequency is not known. Because the attenuation model adopted strongly affects the character of the corrected spectrum, the results of work on this ancillary problem are essential input to the research.

Data from FRM, and SLM, and Florissant (FLO) have been used to determine Q. The first step was to eliminate differences in amplitude caused by differences in crustal structure at the stations. Love wave spectra for an m_b 5.6 earthquake in Oregon (26 Nov 1970) were calculated from seismograms recorded at the three stations. The differences in distances to the three stations were very small compared to the distance itself, so that differences in spectral content could be ascribed to the effect of structure beneath the station. The data from SLM and FLO were found to be almost identical, but quite different from the FRM data. Thus a correction to FRM spectral data was obtained to make them directly comparable to those from the other two stations. Then the Love waves from the m_b 4.6 earthquake in the original data set were used to get Q for the path north from New Madrid. The most remarkable result is that where low values of about 30 were obtained for frequencies near 0.1 Hz, Q rises strongly with frequency above .3 Hz, to reach values of around 300-1000 for frequencies from 0.4 to 3 Hz.

In order to test the method two well recorded earthquakes from Ecuador, the larger of which was m_b 6.7, have been selected for analysis.

In principle, if the spectra are sufficiently well defined to permit the identification of segments of slope 0 (low frequencies), f^{-1}, and f^{-2} at higher frequencies, the fraction of the effective stress that is relieved by the event can be calculated. The quality of the data to date have not permitted this approach to be exploited. However, an alternate approach is to define the frequency at which the zero slope segment and the f^{-2} segment, projected, intersect and determine the ratio of the spectral amplitude at this frequency to the low-frequency amplitude. The fractional stress drop can be calculated from this ratio, which is $\frac{1}{2}$ for 100% stress drop, and decreases with decreasing fractional stress drop. The necessary equations for this process have been derived, and the application of them to real data has been initiated.

The point of using records of deep earthquakes recorded at short distances is that with the angle of incidence near zero, the effect of the crust can be easily removed and the spectrum in the mantle recovered. The event must be deep enough that sufficient time passes between the arrival of the P-phase and later wave types to permit the evaluation of the long period part of the P-wave spectrum. Only one earthquake, recorded at Antofagasta, Chile, has been processed completely, but the results are very encouraging. Very severe constraints on the relative positions of the station and hypocenter with respect to regional dip of the crust-mantle boundary limit the number of events available for processing by this approach. For example, even after a lengthy search, no events in the Tonga-Fiji seismic zone were found to have produced usable data.

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Section 4

Regional Seismicity, New Madrid Seismic Zone.

C. Kisslinger

The continued program of observation of earthquakes in the New Madrid seismic zone is aimed at obtaining a data set suitable for studying small earthquakes from a variety of viewpoints. In terms of the current needs of the VELA-Uniform program, the broader understanding of the properties of small earthquakes is important. In addition, these earthquakes occur in one of the few mid-continental seismically active areas of the world, and their relation to regional or global-scale tectonic processes is unknown.

The basic data or the smallest events come from the three stations in western Tennessee, Lassiter, Samburg, and Tiptonville. The basic layout of the network was described in the previous annual technical summary. Since that report was written, the system has been changed to use hardwire telemetry from all stations to Tiptonville, where all three stations are recorded on magnetic tape. Samburg and Lassiter are 11.4 km apart, on Tertiary rock east of Reelfoot Lake, and Tiptonville is 18.4 km from both, in the flood plain near the New Madrid bend in the Mississippi River. The conversion to telemetry caused an interruption in operation in the fall of 1970, but recording has been essentially continuous since January, 1971. Data from the Samburg station was lost for two weeks in August as a result of damage to the electronics in the recording trailer caused by rifle fire into it, presumably by hunters roaming through the area. The magnification curves of the instruments peak at about 10 Hz, with values of 330K at Lassiter, 190K at Samburg, and 70K at Tiptonville. The low gain at Tiptonville is forced by the high noise on the alluvium.

In addition to this local network, data from the entire Saint Louis University network are available for investigation of the more energetic events. In particular, the long-period instruments at Flat River, St.Louis and Florissant provide fairly broad-band coverage in the distance range of 200 to 300 km.

All events found on at least two of the network records have been catalogued, and all giving reliable times on at least the three network seismographs located. Naturally, the better locations are for events that could be detected at other stations in the region

(especially Greenville, as well as the permanent stations). The locatable events for the period March-May 1970 and January-March 1971 are roughly distributed along a northeast-southwest trending line that parallels the direction of faulting in the region that has been derived from well data and geophysical surveys. Most of the activity is in Missouri, southwest of New Madrid. The activity is centered in two clusters, one around the New Madrid bend in the river, the other near the Missouri-Arkansas border. A 1200 km^2 zone in which no activity has been located will be watched carefully for events in the future.

Among the interesting phenomena noted is the fact that in this region in which aftershocks are rare, evidence of foreshocks has been found. In one case an m_b 2.5 event preceded an m_b 3.5 earthquake by one hour and 23 minutes. In another case an m_b 1.7 event was preceded by two small events, and followed by one, all within six minutes.

The magnitudes of 50 events definitely identified as earthquakes have been determined. The magnitude-frequency of occurrence curve has a slope of -0.6, exactly the value found for this region in an independent study concerning a different time interval by a team from Lamont-Dougherty Geological Observatory.

Section 5

Model Studies of Explosion-Generated Waves.

C. Kisslinger, A. Grover, and I. N. Gupta

Model investigations using explosive sources were directed to two problems: the effect of previously exciting stress on the resulting seismic signal and further studies on decoupling.

Previous work by Kim and Kisslinger (1967) had established the general characteristics of the signals produced by explosions in two-dimensional media in uniform tension. The new work was intended to seek clarification of the effect of a non-uniform ambient stress field on the resulting waves. The field was created in a rhomboid-shaped Plexiglas sheet subjected to tension at opposite corners. The distribution of stress was determined photostatically and by evaluation of appropriate theoretical expressions.

Small explosive charges were detonated at various points in the plate, including one case in which a linear zone of weakness had been introduced in the form of a groove cut partly through the sheet. The resulting seismic waves were detected at the edges of the plate by means of capacitor pickups. Amplitudes were corrected for angle of incidence at the receiver and geometrical spreading.

Cracks triggered by the explosion generated detectable stopping phases. The crack propagation velocity derived from the data was 0.6 times the shear velocity. The orientations of cracking were close to the computed direction of maximum shear stress around the shot hole and close to the normal to the applied tensile stress. Attempts to explain the modification of body wave generation resulting from prestress were not very successful. Previous results of Kim were confirmed in that the azimuthal symmetry of the P-wave was altered and S-wave amplitude increased with increasing prestress.

In all cases the elastic wave energy proceeding directly from the explosion so dominated the seismograms that determination of the contribution from strain release and crack formation was not very satisfactory. The prominence of the S-waves appears to be the best indication that the medium was prestressed.

As an extension of previous work by Bahjat and Kisslinger (1969, 1970) three-dimensional models were used to explore the effect of the medium around the explosion on the radiated signal. A series of cavities of different sizes were formed inside a block of plaster-of-Paris, using a technique described in Bahjat and Kisslinger (1970). Differences in the signal for air-filled cavities and cavities filled with Ottawa sand were sought.

In previous work the signal in the shot medium was known from observation and could be used as input to the decoupling problem. In this work, however, extreme difficulty was encountered in trying to record the waveform in the sand itself. It proved impossible to employ the capacitor detectors in the cohesionless material in such a way as to get a true measure of the motion in the mass of sand. It was possible to measure the P-velocity in the sand. Therefore, the only quantitative interpretation of the data that was feasible was the determination of the geometric effect of the cavity as a resonator, after the approach of Bahjat and Kisslinger (1969). Theoretical curves for the transfer function of the sand-filled cavities were calculated from a simplified model.

Comparison of the signals and the corresponding spectra for a tightly coupled sheet in plaster-of-Paris and for air-filled and sand-filled cavities with radii of 0.8 and 2.54 cm lead to the following general conclusions:

a) the air-filled cavities produced decoupling at the higher frequencies of about 1/10,

b) the introduction of the sand into the cavity resulted in larger signals than for air, especially at the lower frequencies. Peak amplitudes in sand reached about 10 times the amplitude of the tightly coupled shot,

c) the presence of the sand boosts the low frequency energy preferentially, producing an easily-seen lengthening of the dominant P period. For these cavities the dominant frequency with sand in the cavity was about one-half that for the air-filled cavity.

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