Comptes Rendus N° 13

CONSEIL INTERNATIONAL DES UNIONS SCIENTIFIQUES

UNION GÉODÉSIQUE ET GÉOPHYSIQUE INTERNATIONALE

ASSOCIATION DE SÉISMOLOGIE ET DE PHYSIQUE DE L'INTÉRIEUR DE LA TERRE

COMPTES RENDUS DES SÉANCES DE LA DOUZIÈME CONFÉRENCE

RÉUNIE A HELSINKI DU 25 JUILLET AU 6 AOUT 1960

Rédigés par le Secrétaire Général Associé Markus BÅTH

Publiés avec le concours financier de l'UNESCO

Société Nouvelle d'Impression
MÜH-LE ROUX - Strasbourg
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GENERAL ASSEMBLY AT HELSINKI

(July 25 - August 6, 1960)

SESSIONS OF THE INTERNATIONAL ASSOCIATION OF SEISMOLOGY AND THE PHYSICS OF THE EARTH'S INTERIOR

MONDAY, JULY 25

All day : a) 1st Session : Geochemistry (organised by CIGAR, with participation of IASPEI).

b) 2nd Session : European Seismological Commission.

TUESDAY, JULY 26

Morning : Formal Opening and First Plenary Session of the IUGG.

Afternoon : 3rd Session : Presidential Address by Sir Harold Jeffreys.

WEDNESDAY, JULY 27

Morning : a) 4th Session : Rock Age Determinations (organised by CIGAR, with participation of IASPEI).

b) 5th Session : Results from Seismic Records of Large Explosions.

Afternoon : a) 6th Session: Rock Age Determinations; cont. (organised by CIGAR, with participation of IASPEI).

b) 7th Session : Organisation, reports, etc.

THURSDAY, JULY 28

Morning : 8th Session : Organisation (publication of IGY results).

Afternoon : a) 9th Session : Islands Arcs (together with IAG and IAV).

b) 13th Session : Constitution of the Continental Crust ;

FRIDAY, JULY 29

Morning : 11th Session : Constitution of the Continental and Oceanic Crust.

Afternoon : a) 12th Session : Ocean Floor (together with IAPO).

b) 13th Session: Constitution of the Continental Crust ; cont.

SATURDAY, JULY 30

Morning : 14th Session : Seismological Geography.

MONDAY, AUGUST 1

Morning : 15th Session : Seismological Geography and Energy of Earthquakes ; cont.

Afternoon : a) 16th Session : Tsunamis and Storm Surges (together with IAMAP and IAPO).

b) 17th Session : Constitution of the Continental and Oceanic Crust ; cont.

TUESDAY, AUGUST 2

Morning : 18th Session : Seismic Wave Propagation.

Afternoon : 19th Session : Seismic Wave Propagation ; cont.

WEDNESDAY, AUGUST 3

Morning : a) 20th Session : Bodily Tides (together with IAG).

b) 21st Session : Fault-plane Work and Source Energy.

Afternoon : 22nd Session : Ultra-long-period Motions in the Earth and Recent Movements of the Earth's Crust (together with IAG).

THURSDAY, AUGUST 4

Morning : 23rd Session : Instruments.

Afternoon : a) 24th Session : Organisation, etc.

b) 25th Session : Recent Movements of the Earth's Crust; cont. (together with IAG).

FRIDAY, AUGUST 5

Morning : a) 26th Session : Recent Movements of the Earth's Crust; cont. (together with IAG).

b) 27th Session : Internal Constitution of the Earth.

Afternoon : a) 28th Session : Internal Constitution of the Earth ; cont. (together with IAG).

b) 29th Session : Seismic Wave Propagation ; cont.

SATURDAY, AUGUST 6

Morning : Second Plenary Session of the IUGG and Formal Closing of the Assembly.

LIST OF PARTICIPANTS IN THE SESSIONS OF IASPEI

(July 25 - August 6, 1960)

Remarks. — The following list has been made according to the lists, which were circulated during the sessions and which have been completed as far as possible. The figures refer to the number of the sessions, as listed above. There are no lists of participants available for the sessions 1, 2, 4, 6, 20, and 28.

Abdulla, M. A. (Sudan):	9, 23.
Abelson, P. H. (USA):	9, 17, 21.
Abubakar, I. (Nigeria):	12, 15, 17, 18, 19, 22.
Adams, L. H. (USA):	3.
Adams, W. M. (USA):	5, 8, 9, 11, 13, 14, 15, 18, 21, 22, 23, 25.
Aitken, J. M. (USA):	17.
Aki, K. (USA):	3, 5, 8, 9, 13, 14, 17, 18, 19, 21, 22, 23, 24, 27, 29.
Aldrich, L. T. (USA):	13.
Alikoski, H. A. (Finland):	25, 26.
Allan, T. D. (Italy):	9, 12, 17.
Alldredge, L. R. (USA):	16.
Allen, C. R. (USA):	9, 14.
d'Arnaud Gerkens, J. (Holland):	9, 12, 17, 18, 21, 22, 23, 27.
Arnold, K. (Germany-DR):	25, 26.
Asplund, L. (Sweden):	25, 26.
Atherton, N. (UK):	9, 12.
Austin, T. (USA):	16.
Backus, G. (USA):	3, 5, 10, 17, 18, 21, 22, 27.
Bader, R. G. (USA):	12.
Bahnert, G. (Germany-DR):	22.
Bailey, L. F. (USA):	3, 5, 7, 10, 11, 13, 15, 17, 18, 19, 21, 22, 23, 24, 25, 27, 29.
Balavadze, B. K. (USSR):	3, 5, 8, 9, 11, 15, 17, 24.
Balay, M. A. (Argentina):	16.
Ball, F. K. (Australia):	27.
Balle, L. (Denmark):	22, 25, 26.
Balsley, J. R. (USA):	3, 5, 11, 13, 15, 23, 27.
Baranov, V. (France):	9, 19, 22.
Barnett, M.A.F. (New Zealand):	16.
Barone-Adesi, V. (Italy):	8, 11, 17, 21, 23.
Basurto, J.:	5.

GENERAL ASSEMBLY AT HELSINKI

(July 25 - August 6, 1960)

PROCEEDINGS OF THE SESSIONS

1st SESSION

MONDAY, JULY 25 (all day)

Program

1. — Scientific communications : Geochemistry.

This symposium was organised by CIGAR, with participation of IASPEI. The proceedings, as prepared by Prof. R. D. Russell, are published in the *Trans. Amer. Geophys. Union,* December 1960, pp. 641-642.

2nd SESSION

MONDAY, JULY 25 (all day)

MEETING OF THE EUROPEAN SEISMOLOGICAL COMMISSION

As the complete proceedings of this meeting will be published elsewhere, we give here only the resolutions adopted (See IUGG Chronicle, May 1961).

Resolution 1 : Project of the Seismicity of Europe

The European Seismological Commission adopts at its session in Helsinki the following resolution concerning the project of the Seismicity of Europe :

1 — To ensure the further development of the project all countries should :

a) prepare the catalogues of earthquakes for the interval 1801-1900 (Io $\geqslant$ VII) and for the years prior to 1800 (Io $\geqslant$ IX),

b) compile the statistics of shocks with Io $<$ VI for intervals where the material is homogeneous,

c) send results sub a) and b) not later than July 1, 1961, to Mr. V. Kárník, Praha,

d) begin with the preparation of maps of seismic zoning for the interval 1800—1960 (max. isoseismals) marking the number of observations.

2. — ESC recommends the creation of an international center in Praha, where all information and publications concerning the seismic activity in the European area should be available. ESC appeals to all countries to forward all new publications and to help in the completion of old publications and bulletins which are still missing.

3. — Considering the great extent and complexity of problems to be solved in the framework of this project the ESC agrees that the President of the special Subcommittee invites European seismologists or institutions for a participation in solving some special problems (particularly : intensity, magnitude, energy, unified methods of earthquake classification, estimation of accuracy of hypocenters, relation between macroseismic and microseismic results...).

4. — The progress report and the first drafts of the epicenter maps, which were adopted by the Commission, will be distributed by Mr. V. Kárník after the Helsinki meeting (not later than October 30, 1960) to members of the ESC. The ESC asks the IUGG to take care in order to publish the progress report and the first epicenter maps.

5. — ESC charges prof. V. V. Beloussov to prepare in collaboration with V. Kárník a scheme of seismotectonic division of the European area and to present it at the next session.

Resolution 2 :

The European Seismological Commission has been informed on the first contacts concerning the creation of the Sub-Commission for the study of the Carpathian region.

The ESC demands that the constitution of this Sub-Commission and its first meeting should be realised as soon as possible.

Professor Savarensky is charged to elaborate a programme of work of the Sub-Commission and to present it to the ESC.

In a letter of November 1, 1960, Mr. V. Kárník gives the following additional remark to Resolution 1 :

If *homogeneous* data for earthquakes with Io < VII (1801-1900) or Io < IX (prior to 1800) are available, they should also be included into the national catalogues. The statistics (1b) can be prepared not only for limited intervals but also for limited *areas*. I propose to prepare the draft of the map of seismic zoning (1d) by tracing the generalized maximum isoseismals determined on the basis of the effects of all known earthquakes with Io ⩾ VI. The different frequency of occurrence (number of observations e.g. 1, 2-3. 4-7, 8-15, > 15) can be represented e.g. by shading the corresponding areas.

See also paper 56 in the 14th Session and IUGG Monograph No. 9, 1961, 31 pp.

3rd SESSION

TUESDAY, JULY 26 (afternoon)

PRESIDENTIAL ADDRESS

The session was opened at 15.00. In the presence of a large audience *President Sir Harold Jeffreys* gave his presidential address on "Rock Creep and Tidal Friction" to the Association of Seismology and the Physics of the Earth's Interior. The complete text of the presidential address is given below.

The session was closed at 16.00.

ROCK CREEP AND TIDAL FRICTION

by SIR HAROLD JEFFREYS

(Presidential Address to the International Association of Seismology and the Physics of the Earth's Interior, Helsinki, July 26, 1960)

The Association of Seismology has included the Physics of the Earth's Interior among its activities since 1948, and for the present occasion I have chosen a topic concerned with that subject. I have also a personal concern with it because my earliest work was in the search for imperfections of elasticity in the Earth and Moon at small strains, and I have always been seeking for definite evidence of such imperfections that would make it possible to specify their type and amount.

The Moon's attraction on the oceans pulls the surface out of shape, and produces the tides. But in addition, it is greater on the near side, and this distorts the whole body of the Earth because the Earth is elastic. This effect is small but just big enough for people to have tried to measure it as early as 1870; but what they actually discovered were microseisms. Useful measures were first obtained about 1900 and much more accuracy is being attempted as part of the I.G.Y. programme.

If the Earth was perfectly elastic or perfectly fluid it would be stretched directly along the line of centres. But if there is any imperfection of elasticity the tide will be out of phase. The greatest elevation at a place will be after the place has passed below the Moon. Then the Moon's attraction on the tides slows up the Earth's rotation, and the reaction accelerates the Moon. The latter does not show up directly because it provides a steady increase of energy, which can be accommodated only by increasing the distance and decreasing the angular velocity. For a circular orbit under gravitation the gain of potential energy is twice the loss of kinetic energy.

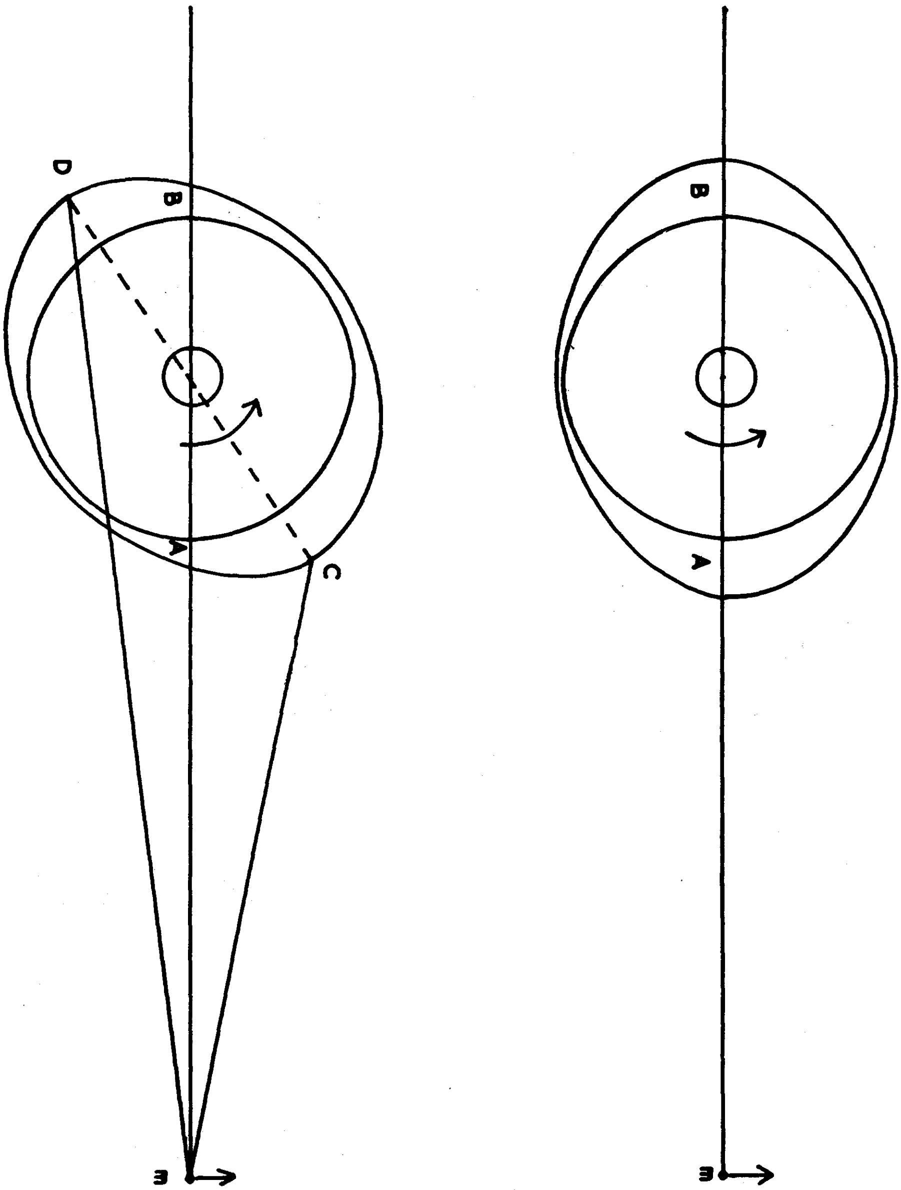


Figure 1

On the other hand astronomical time is determined from the rotation of the Earth. If the Earth lags, it takes a longer time for a fixed longitude to pass under a given star. In the meantime the Sun and Moon have travelled some distance in the sky, and the resultant effect is that they appear to have secular accelerations. These can be measured from comparison of ancient and modern observations, the former mainly of eclipses.

A satellite will have its rate of rotation reduced if it is faster than the rate of revolution, and accelerated if it is slower. The ultimate state is when it keeps a constant face to its primary. This state has been reached by the Moon and Mercury and by all the satellites of Mars, Jupiter and Saturn whose rotations are known, with the possible exception of J III. Tidal friction is the only explanation that has been suggested for this state. However, for a long time the explanation was only qualitative. Cosmogonists, when they find a body rotating more slowly than they expect, usually say "tidal friction" and say no more. But this is not satisfactory : we need to state a definite form of imperfection of elasticity and show it quantitatively capable of explaining the queer things that we observe.

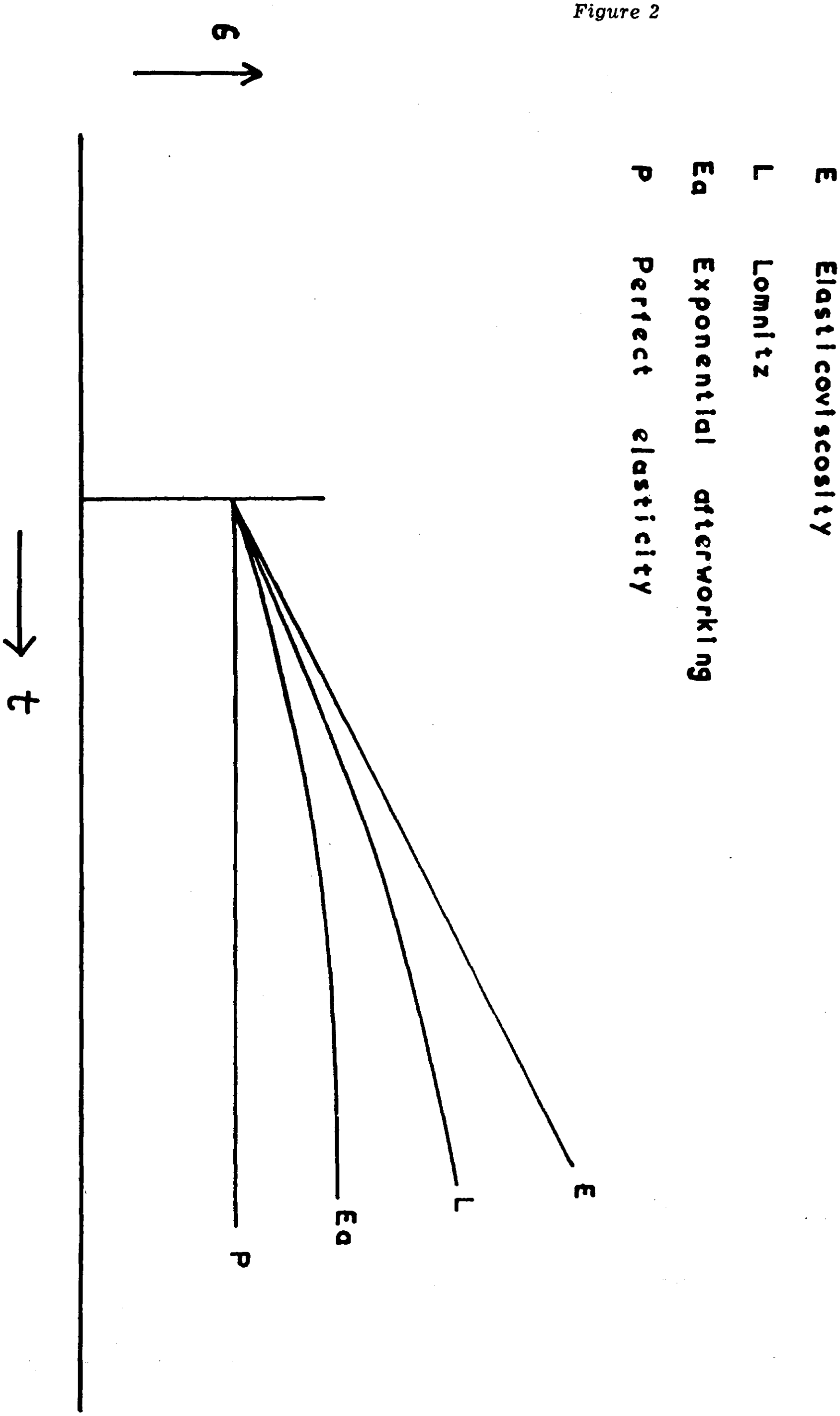
The theory was worked out in great detail by Sir George Darwin, but he was hampered by lack of quantitative geophysical data. He usually treated the Earth as a viscous liquid and took the viscosity to be such that the changes would be as rapid as possible. However he occasionally made use of a law of imperfect elasticity proposed by Maxwell and expressed in equations of motion by Butcher. It is known as elasticoviscosity. According to this if a shear stress P is applied at time 0 and kept constant the strain is

$$\varepsilon = \frac{P}{\mu}\left(1 + \frac{t}{\tau}\right);\ t > 0.$$

This is easily adapted to variable stress. For short periods there is effectively a rigidity μ ; for long-continued stresses the material behaves like a liquid of viscosity $\mu\tau$.

There is a free oscillation of the Earth's axis known as the free nutation, predicted by Euler, which would have a period of 305 days if the Earth was rigid. The actual period is about 430 days, and the difference is due to the fact that the Earth is elastic. By 1910 or so it became possible to use this to estimate the average rigidity of the Earth, which is rather more than that of the stiffest rocks at the surface. But with any imperfection of elasticity this motion will be damped, and I found in 1916 that if τ was chosen to fit the secular acceleration of the Moon the free nutation would be damped out in a few days. This was a major difficulty, but G. I. Taylor in 1917 found that the dissipation in the tides of the Irish Sea was such that about 50 Irish Seas would account for the whole of the secular acceleration. I took data for other seas from the Admiralty Sailing Directions, and found that there really were the equivalent of 50 Irish Seas, and it appeared that the whole secular acceleration might well be due to dissipation in shallow seas with strong tidal currents. Such seas would hardly affect the free nutation and the difficulty about its damping was considered solved. There was no evidence at all for imperfection

Figure 2



E Elasticoviscosity
L Lomnitz
Ea Exponential afterworking
P Perfect elasticity
σ
t
E
L
Ea
P

of elasticity in the interior of the Earth at strains of the order of 10^{-7}. However the problem for the Moon and Mercury remained; there was every reason to suppose that they never had seas, and tidal friction in them must be bodily, and there must be some dissipation even for strains of this order.

As the strain in a rock on the verge of fracture is of the order of 10^{-3}, it seemed reasonable to hope that at strains of order 10^{-7} the stress-strain relation would be linear. Then if the solution for perfect elasticity is known it can be adapted easily to any law of imperfect elasticity; we need only replace the rigidity by a Heaviside operator. Also if the relation is

$$\varepsilon = P\ f(t)$$

for a constant stress applied at $t = 0$, the generalization for variable stresses is just

$$\varepsilon = \int_{\xi=-\infty}^{t} f(t-\xi)\ d\ P(\xi).$$

There has been great difficulty in finding positive evidence for imperfection of elasticity in the Earth at small strains, but some has at last appeared in the damping of the free nutation. Determining this is a difficult statistical problem. The damping has to be disentangled from the irregular disturbances that keep the motion going, but it appears that if the motion was left to itself it would have its amplitude reduced in the ratio e to 1 in something between 10 and 30 years. This would imply that for a period of 430^d the strain lags behind the stress by an angle of about 1/40.

Other evidence was obtained in direct tests on rocks by D. W. Phillips and D. T. Griggs. Phillips studied bending of bars at strains down to 10^{-5}. His results suggested that the creep law at small stresses might be of the form

$$\varepsilon = \frac{P}{\mu}\left[1 + \left(\frac{\tau'}{\tau} - 1\right)\left(1 - e^{-t/\tau'}\right)\right]$$

with $1 < \tau'/\tau < 1.6$ As a trial value for further investigation I took $\tau'/\tau = 1.1$. Then the condition that the lag for a period of 430^d is 1/40 gives two solutions :

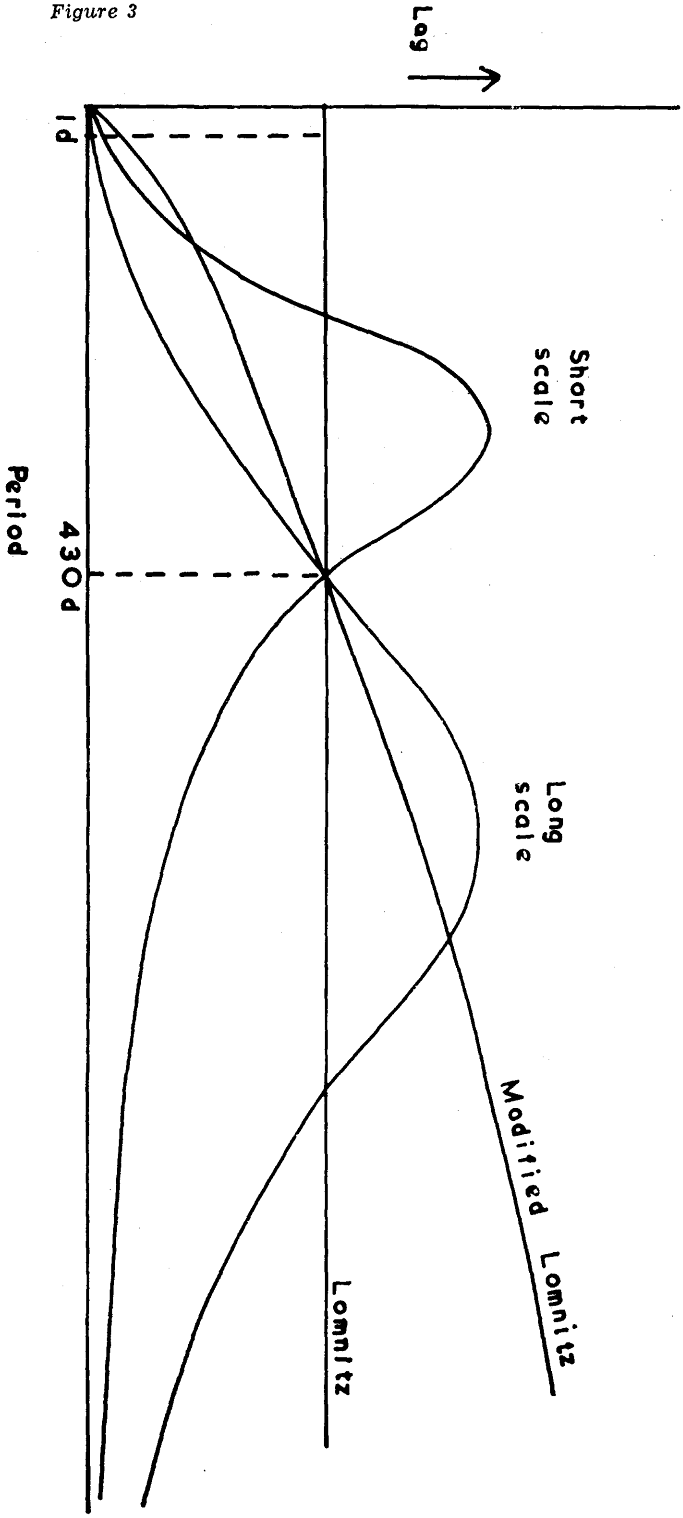
$$\tau = 17.0^d,\quad \tau' = 18.7^d,$$

and $$\tau = 251^d,\quad \tau' = 276^d.$$

I call these the short and the long time-scales. They were at least sufficiently precisely stated for their consequences to be worked out. They could be tested on the Moon, Mercury, and the two satellites of Mars, which probably have constitutions similar to the Earth's rocky shell.

The chief result was that if Mercury ever rotated as fast as the Earth, the long time-scale would not give enough dissipation to account for the present rotation. Whether it could for the Moon was doubtful. Later work suggests that it is also doubtful whether the short time-scale would succeed for Mercury.

Figure 3



Log
1d
430d
Period
Short scale
Long scale
Modified Lomnitz
Lomnitz

With the elasticoviscous law we can put $\tau' = \infty$ and estimate τ to fit the damping of the free nutation, but it is even more incompetent than the long time-scale to account for the rotations.

The Moon, like the Earth, is not quite a sphere, and the attraction of the Earth on its equatorial bulge keeps its axis at a constant inclination to its orbit. This bulge is only about 1 part in 1600, but is known to about 1 per cent. If the Moon was elasticoviscous the bulge would subside as e to 1 in about 400 years. The Moon's inclination of axis would have changed greatly even in the time of accurate observation. There are analogous difficulties for the Earth, but they cannot be stated quite so precisely, because we do not know the departures from the hydrostatic state so accurately.

After this work was done I attended the Toronto meeting of the I.U.G.G. in 1957; there an important contribution was made by C. Lomnitz. Many laboratory workers on metals and rocks have maintained that the creep under constant stress does not tend to a constant after a long time, as Phillips's results suggested. There is no experimental support for elasticoviscosity, but increases like $t^{1/3}$ or log t have been found. These have the obvious fault that initially $d\varepsilon/dt$ would be infinite, which is not true even for a liquid. But Lomnitz pointed out that this can be avoided easily. If

$$\varepsilon = \frac{P}{\mu}\left\{1 + q\log(1 + at)\right\},$$

with q, a positive constants, the behaviour after a long time is like log t. In his experiments on rocks, with ε of order 10^{-5}, the stress-strain relation was linear. He got a about 6000/sec., q from 0.001 to 0.01. The law can be modified to

$$\varepsilon = \frac{P}{\mu}\left[1 + \frac{q}{\alpha}\left\{(1 + at^{\alpha}) - 1\right\}\right]$$

which would give behaviour like t^{α} after a long time. These laws are intermediate between elasticoviscosity and exponential elastic afterworking : the creep after a long time tends to infinity but not nearly so fast as t.

For periodic forced disturbances with periods longer than 10^{-3} sec. the Lomnitz law gives a nearly constant lag of $\frac{1}{2}\pi q$. But it has an unfortunate consequence. If we choose q to fit the damping of the free nutation we find that an S wave would have its beginning blunted to such an extent as to become unreadable. But with the modified form we can both fit the free nutation and have an S at 80° with a beginning that is readable within 2^{s}. I originally found that this implies $\alpha = 0.17$, but in a recalculation I get $\alpha = 0.25$. The method rests on two data that refer to most of the Earth's shell, since an S wave at this distance has been nearly down to the core, and it should be legitimate to combine them. The behaviour of the lags for other periods is as shown in Figure 3.

There is good reason to suppose that the Moon, Mercury, and Mars and its satellites are mainly rocky, and hence that the same law should be applicable to them. We have many checks on this.

Theoretically the Moon's axes have three possible free oscillations in direction. These are all too small to have been observed. The law gives decays of amplitude as e to 1 in from 4×10^4 to 7×10^5 years.

Tidal dissipation in the Earth's shell can account for about 8 per cent of the apparent secular acceleration of the Moon ; this is consistent with most of the secular acceleration being due to turbulence in tidal currents.

If Mercury originally rotated in 1 day it could be made to keep a constant face to the Sun in about 4×10^9 years. The corresponding time for the Moon, even if we do not allow for changes in its distance, is about 10^8 years. For the satellites of Mars the results are similar. So the law explains the relevant things that have happened.

But this is not enough. For a scientific law to be satisfactory it must not only explain things that have happened ; it must also not explain things that have not happened. This is a consideration that many scientists forget. I mentioned earlier that the elasticoviscous law would imply that the Moon's ellipticities would subside in a few hundred years. The modified Lomnitz law implies that in 3×10^9 years about 80 per cent of an original ellipticity would survive. Elasticoviscosity in the Earth would imply total absence of low harmonics from the gravitational field ; but such harmonics are present. According to the modified Lomnitz law a harmonic of degree 2 would retain half its amplitude for 10^8 years and about 20 per cent for 3×10^9 years.

Exponential elastic afterworking, with the short time scale, was the first suggested law of imperfect elasticity that did not break down the first time it was applied beyond the original data. However, it is doubtfully enough to account for the rotation of Mercury, and it failed to account for the blunting of earthquake pulses as they travel. For the latter, scattering was available as an alternative explanation, but was an *ad hoc* hypothesis unverified otherwise. The modified Lomnitz law fits both data.

I offer a few remarks on uncertainty of the data. The ratio of the time-scales for seismic waves and the Eulerian nutation is of order 10^7. A similar factor applied again brings up to 10^7 years, which is long enough to be of geological interest. So the extrapolation is not really wild. The rate of damping of the Eulerian nutation has been taken to corresponding to a time of relaxation of 15 years. It may easily be as short as 10 years or as long as 30 years, and I understand that even longer times of relaxation have been found by Russian workers from observations at observatories not in the International Latitude Service. But if the damping was more rapid it might be harder to understand the persistence of the Moon's ellipticities. Tidal friction concerns periods of order 1^d, and if the damping was much slower the rotation of Mercury would be harder to understand. So, though the data are not as accurate as we should like, it seems that they could not be greatly altered without introducing difficulties.

On the other hand the law need give no encouragement to advocates of continental drift and convection currents in the Earth's shell. Under constant stress it makes the rate of creep tend to zero with increasing time. In convection currents the shear stresses that maintain the currents are nearly constant, and therefore the currents themselves must fall off. But the hot columns that tend to rise and maintain convection are maintained by these very currents flowing in below, and if their speed declined the hot columns themselves must disappear.

One conclusion to be drawn is that the elasticoviscous law, as applied to the Earth and the inner planets, is dead, and all conclusions based on it relating to post-glacial uplift, polar wandering, continental drift, and convection currents are totally erroneous.

4th SESSION

WEDNESDAY, JULY 27 (morning)

Program

1. — Scientific communications : Rock Age Determinations.

This symposium was organised by CIGAR, with participation of IASPEI. So far, no decision has been reached concerning the publication of the proceedings of this symposium. A summary report has appeared in the *Geophysical Journal,* Vol. 3, No. 4, Dec. 1960, pp. 470-474.

5th SESSION

WEDNESDAY, JULY 27 (morning)

Program

1. — Scientific communications : Results from Seismic Records of Large Explosions.

   1. — *D. E. Willis* and *J. T. Wilson :* Seismic waves generated by high explosives.

   2. — *J. Oliver* and *M. Ewing :* Seismic waves generated by nuclear explosions in various environmental conditions.

   3. — *M. Båth :* Records of explosions, nuclear and chemical (energy computations, maximum recording range, etc.).

   4. — *A. L. Latter, R. E. LeLevier, E. A. Martinelli,* and *W. G. McMillan :* A method of concealing underground nuclear explosions.

5. — *W. M. Adams* and *D. S. Carder :* Seismic decoupling for explosions in spherical cavities.

6. — *L. Grinda :* Un effet particulier d'une explosion sous-marine et plus spécialement d'une explosion en pleine eau.

7. — *P. Pomeroy* and *J. Oliver :* Seismic waves from high-altitude nuclear explosions.

8. — *W. H. Diment, S. W. Stewart,* and *J. C. Roller :* Seismic observations of nuclear explosions at the Nevada test site at distances of 5 to 300 kilometers.

9. — *G. W. Johnson :* Application of nuclear explosions as seismic sources.

10. — *F. Press :* Spectrum analysis and mode ratios of surface waves from earthquakes and explosions.

11. — *J. T. Wilson* and *D. E. Willis :* Frequency spectra of seismic waves generated by earthquakes and explosive blasts.

12. — *H. F. Birkenhauer,* S. J. : Statistical studies of blasting vibrations.

The session is opened at 9.10 with *Prof. Bullen* as chairman.

1. — Scientific communications : Results from Seismic Records of Large Explosions.

1. — *Prof. James T. Wilson* gives the paper by *D. E. Willis* and *J. T. Wilson :* Seismic waves generated by high explosives.

The maximum vertical ground displacement for periods less than 2 seconds is presented for a series of explosions ranging in size from 1 ton to 19 kilotons at distances varying between 1 and 1000 kilometers. These ground displacements have been normalized to the Rainier (1.7 kt) underground nuclear shot, using an approximate first-power relationship between the maximum vertical component of ground displacement and the charge size which was determined from a number of quarry shots.

Empirical equations can be used to describe the observed data. The maximum displacement was found to decrease as a function of the inverse 3/2 power of the distance out to distances of approximately 200 kilometers and as the inverse 1/2 power of the distance plus an appropriate absorption factor for distances between 400 and 1000 kilometers.

A limited study of a 30 ton shot disclosed that the attenuation of the P waves between 16 and 100 kilometers could be expressed in terms of spherical spreading with a reasonable absorption factor.

This work was supported by Project Michigan under Department of the Army, Contract DA-36-038-SC-(78801), administered by the U.S. Army Signal Corps, and the Office of Naval Research under Contract Nonr-1224(33).

The paper has been published in slightly different form under the title "Maximum vertical ground displacement of seismic waves generated by explosive blasts", *Bull. Seism. Soc. Amer.*, Vol. 50, No. 3, 1960, pp. 455-459.

2. — *Dr. Oliver* reads the paper by *J. Oliver* and *M. Ewing :* Seismic waves generated by nuclear explosions in various environmental conditions.

Long-period seismic waves generated by large nuclear explosions may be detected by seismographs at great distances from the source. In general, the nature of these waves may be determined through comparison with information on wave propagation within the earth as known from studies of natural earthquakes.

The following kinds of long-period waves were generated by one or more nuclear explosions : Rayleigh waves of the fundamental and first shear (or M_2) modes for both continental and oceanic structures ; Love waves of the fundamental mode for continental structure ; body waves of the P and S types as well as combinations of these types for paths including one or more reflections. Since the locations of some of the explosions are known more precisely in time and space than are the foci of natural earthquakes, and since some of these waves are not recorded when the source is a natural earthquake, the data from explosions provide valuable supplementary information on wave excitation and propagation and on earth structure.

The paper has been published in *Science,* Vol. 131, No. 3416, June 17, 1960, pp. 1804-1805.

3. — *Dr. Båth* presents his paper on "Records of explosions, nuclear and chemical (energy computations, maximum recording range, etc.)":

Energies computed by means of the seismic records of the Swedish stations have been compared with the total explosive energy in those cases, where information is available. The seismic energy is of the same order of magnitude as the total explosive energy for underwater explosions, provided the water cover is at least several tens of meters thick. For underground explosions the energy transfer is more variable, and is similar to an underwater explosion only when there is a good contact between explosive and surrounding rock. For explosions on or near the surface, the seismic energy amounts to only about one thousandth of the total energy.

A relation has been derived between the Gutenberg-Richter magnitude *M* of explosions and the maximum recording ranges *Dm,* provided records at the most sensitive stations of the world are considered :

Dm	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
M	3.9	4.6	4.9	5.1	5.3	5.4	5.5	5.6	5.6	5.7

Records of nuclear explosions as well as of chemical explosions have been used, and the results are the same for both kinds of explosions.

The complete text has appeared as follows :

1) Seismiska registreringar av explosioner — särskilt kärnvapenexplosioner, *Försvarets Forskningsanstalt,* Avd. 2, Stockholm, Dnr 2441-2092, 1958, 41 pp.

2) Seismiska metoder för upptäckt av kärnvapenexplosioner, *Militär-Teknisk Tidskrift,* Vol. 27, No. 3, Stockholm 1958, pp. 2-5 and 31.

3) Seismiska registreringar av explosioner — särskilt kärnvapenexplosioner, del II, *Försvarets Forskningsanstalt,* Avd. 2, Stockholm, Rapport A 2020-2092, 1959, 25 pp.

A discussion on the three papers presented takes place.

Prof. Press asks Dr. Wilson if he can explain why the amplitude decrease with distance is $r^{-1/2}$ instead of r^{-1} which is expected because of the combined effect of geometric spreading and dispersion.

Prof. Wilson : For the short periods we have been measuring there is little dispersion and the Rayleigh waves are a short train. This perhaps accounts for our not observing an attenuation showing the effects of dispersion.

Dr. Lapwood asks the authors of the papers 1 and 2 whether they found evidence of a decrease in amplitude of Rayleigh waves with increase in depth of focus.

Dr. Oliver : Some data relating to this subject will be presented in a later paper by Dr. Pomeroy (paper no. 7).

Mr. *Kárník* asks Dr. Båth what types of waves and what tables were used in determining the magnitudes.

Dr. Båth : For $\Delta > 15^{\circ}$ the usual procedures for magnitude determination were used ; for $\Delta \leqslant 5^{\circ}$ special energy formulas have been developed.

4. — *Dr. Martinelli* gives the paper by *A. L. Latter, R. E. Le Levier, E. A. Martinelli,* and *W. G. McMillan :* A method of concealing underground nuclear explosions.

The seismic signal from an underground explosion can be greatly reduced by means of a big hole. A theoretical discussion of this decoupling phenomenon will be presented. To maximize the effect, the hole must be sufficiently large to ensure elastic behavior of the surrounding medium. For a nuclear explosive it is estimated that the elastic condition is satisfied if the hole is roughly spherical in shape with a volume of 7×10^4 cubic meters per kiloton of energy release at a depth of approximately one kilometer. The decoupling factor for such a cavity in a hard rock medium like salt, relative to a fully tamped explosion in the Nevada tuff medium, e. g. the Rainier nuclear explosion, is approximately 300. When the yield of the explosion is increased for a fixed hole size, and inelastic behavior of the medium occurs, the decoupling factor is reduced but only in a gradual way.

The paper is published in the *Journal of Geophysical Research,* Vol. 66, No. 3, 1961, pp. 943-946.

5. — *Dr. Adams* reads the paper by *W. M. Adams* and *D. S. Carder :* Seismic decoupling for explosions in spherical cavities.

A series of paired explosions in a salt mine near Winnfield, Louisiana, has been conducted to test a theory by Dr. A. L. Latter concerning seismic decoupling by underground cavities. The theory predicted a decoupling of about 100.

Free-field and surface measurements from an explosion in either a 6-ft — or a 15-ft — radius sphere were compared with similar measurements from a completely tamped explosion. Shot sizes were from 20 lb up to a few tons. Surface measurements were made out to 100 km and covered the frequency range from 0.05 to 100 cps. The experiment confirmed that decoupling does occur. The actual decoupling factor as a function of frequency will be presented and compared with the Latter theory.

This work was done under the auspices of the U.S. Atomic Energy Commission.

The paper is published in *Geofisica pura e applicata,* Vol. 47, No. 3, 1960, pp. 17-29.

6. — *Captain L. Grinda* gives his paper on « Un effet particulier d'une explosion sous-marine et plus spécialement d'une explosion en pleine eau ».

Shots of seismic refraction effected in the Mediterranean with charges of 55 lbs. at small depth and at distances between 40 and 150 km. off Monaco caused seismic waves of strong amplitude modulated at the period of 0.6 sec. whereas the continental waves produced at the vertical of the charge were not detectable by the seismograph at Monaco.

These waves indicate that a considerable portion of the energy from the explosion passes from the sea into the earth in a narrow band very near the coast.

This phenomenon may be explained by the mechanism of the propagation of T waves with the following special circumstances :

— Sub-marine sound channel at small depth.

— Average slope of the sub-marine coast 5° off Monaco.

— Sea floor without relief at the vertical of the explosion.

It must be taken into consideration in expedition of seismic refraction in the sea according to the distance and configuration of the coasts as it can engender seismic waves stronger than those which appear near the vertical of the charge.

The paper will be published in the *Bulletin de l'Institut Océanographique de Monaco.* Papers on related subjects have been published by L. Grinda in

1) *Boll. di Geofisica teorica ed appl.,* Trieste, No. 2, 1959, pp. 161-174.

2) *C.R. l'Acad. Sci.,* Paris, Vol. 250, 1960, pp. 2241-2243.

7. — *Dr. Pomeroy* presents the paper by *P. Pomeroy* and *J. Oliver :* Seismic waves from high-altitude nuclear explosions.

Seismic waves of long-periods were well recorded at epicentral distances as great as 9300 km from the high altitude nuclear explosions, TEAK and ORANGE, which were fired in the Johnston Island area on 1 and 12 August 1958, respectively. At Honolulu, at a distance of approximately 1300 km, the recorded seismic waves may be divided into three types : (1) a normally-dispersed oceanic Rayleigh-wave train in which the wave periods decrease from about 35 to 14 seconds as the corresponding velocities decrease from about 4.1 to 1.6 km/sec, (2) an inversely-dispersed oceanic Rayleigh-wave train in which the wave periods increase from about 6 to 10 seconds as the corresponding velocities decrease from about 1.3 to 1.0 km/sec, (3) a T-phase consisting of waves with periods less than about 0.5 seconds as corresponding to a velocity of 1.47 km/sec.

From the normally-dispersed train, phase and group velocities of waves in the 35 to 14 second period range were computed for the two paths both of which traverse primarily a typical deep oceanic basin. The inversely-dispersed train, although predicted by classical theory, has not been observed in seismograms from (natural) earthquakes.

Surface waves of long periods were recorded at Palisades, New York, from both of the high altitude nuclear explosions and these waves have amplitudes comparable to those generated by the larger of the near-surface explosions in the Marshall Islands. Special instruments in Palisades, not operated for TEAK, indicate that amplitudes for the long period body waves from ORANGE are comparable to those from the Marshall Islands shots. In contrast, seismic body waves of short periods are apparently generated much more efficiently by near-surface explosions than high-altitude explosions.

The complete paper has been published in the *Journal of Geophysical Research,* Vol. 65, No. 10, 1960, pp. 3445-3457.

Dr. Båth : Is there any information on the accuracy of the origin time of the seismic waves, considering the air path ? Is there any evidence of influence of atmospheric layering on the generation of the waves observed ?

Dr. Oliver : The time of incidence of the shock waves on the ground at the epicenter is known within a few seconds, certainly less than five. In our study we assumed the source was very simple and certainly this is an oversimplification. However, there is no good information generally available on the details of the complexity. Your point is a good one and this effect certainly should be considered in later more detailed studies.

8. — *Dr. Diment* gives the paper by *W.H. Diment, S.W. Stewart,* and *J.C. Roller :* Seismic observations of nuclear explosions at the Nevada test site at distances of 5 to 300 kilometers.

Seismograms obtained from nuclear explosions with instruments calibrated for particle velocity in the range 1 to 20 cps indicate that the maximum single component of acceleration scales as the 0.8±0.2 exponent of the yield for explosions in bedded volcanic tuff. Accelerations on alluvium are several times higher than on tuff or bedrock. Maximum accelerations caused by explosions in tuff are roughly ten times greater than those caused by comparable explosions in air at a height of 500 to 750 feet above alluvium several thousand feet thick. Explosions in air in the same place produce identical seismograms except for amplitude which depends on yield, whereas explosions either in air or underground which are separated horizontally by several hundred or a few thousand feet produce seismograms that are quite different in detail.

Travel-time data, based on a 6 km per sec crust over a 8 km per sec mantle, indicate a minimum crustal thickness of about 30 km. The average Bouguer anomaly in the same area is about — 120 milligals and the average altitude of the ground surface is about 1.3 km. Some characteristics of seismograms from nuclear explosions and aftershocks of the Montana earthquake of 1959 are compared.

The information contained in this talk has been, or will be, published in the following articles :

1) *Diment, W.H., Stewart, S.W., and Roller, J.C.,* 1960, Maximum accelerations caused by nuclear explosions at distances of 5 to 300 kilometers : U.S. Geol. Survey Professional Paper 400B (in press).

2) *Diment, W.H., Stewart, S.W., and Roller, J.C.,* Crustal structure from the Nevada Test Site to Kingman, Arizona, from seismic and gravity observations : (in preparation).

3) *Stewart, S.W., Roller, J.C., and Diment, W.H.,* 1959, Maximum accelerations caused by underground nuclear explosions in the Oak Spring formation in area 12 of the Nevada Test Site at distances of 5 to 300 kilometers, a preliminary summary : U.S. Geol. Survey TEI-351, open file report, 45 pp.

9. — *Dr. G.W. Johnson* reads his paper on "Application of nuclear explosions as seismic sources".

The application of suitably emplaced nuclear explosives as sources for the generation of seismic signals has been suggested by many individuals. Much information has already been derived and published concerning the earth's structure and propagation of seismic waves originating from nuclear explosions conducted by several nations as part of their weapons development programs. The effectiveness and value of such sources for these purposes has been clearly demonstrated. The development of techniques for firing nuclear explosions underground such that no radioactivity is released to the atmosphere opens the possibility of using such sources anywhere on earth with safety. The obvious advantages to seismology of the application of nuclear explosives as sources are pre-determinations of exact location, time of detonation, and energy release of the detonation which permit optimum placement of recording instrumentation, proper setting of ranges, and pre- and post-shot calibration. In addition, detailed knowledge of the source characteristics removes this important usual ambiguity in the interpretation of the measurements.

The experience from eight underground detonations extending in energy release from about 500 tons to 20 kilotons will be summarized. The general close-in phenomenology will be described. The demonstrated methods of emplacement and stemming to assure containment of radioactivity, will be discussed.

The proposed future Plowshare experiments will be described with their relationship to seismology.

I feel it very desirable that plans be developed for one or more nuclear detonations as sources for international experiments in seismic research.

The paper has appeared as a report from *University of California, Lawrence Radiation Laboratory*, Livermore, California, UCRL-6030-T, 1960, 23 pp. plus figures and tables.

10. — *Prof. Press* presents his paper on "Spectrum analysis and mode ratios of surface waves from earthquakes and explosions".

The mechanism of an earthquake or explosion is important in determining the spectra of the different wave modes as well as the relative energy in each of the modes (e. g. the energy ratio of Love waves to Rayleigh waves). The time duration of the source action, the effective volume of the source, the nature of force system are significant factors. Results of some preliminary experimental studies of spectra and mode ratios from earthquakes and explosions are presented.

In addition, *Prof. Press* presents the recent results from Pasadena concerning free vibrations of the Earth, generated by the Chilean earthquakes in May, 1960. The largest of these occurred on May 22, 1960, 19.11.20 GMT, at 38°S, 73 ½°W (USCGS); Magn. = 8.5. — This information gives rise to a lively discussion.

Prof. Bullen asks for evidence of 100 min period waves.

Prof. Press : There are minor spectral peaks between 53 min and the Earth tide, some in the vicinity of 100 min, but these are not as striking as the peaks described.

Prof. Slichter : The Chilean earthquakes were observed by LaCoste-Romberg earth-tide meter at the Institute of Geophysics, University of California, Los Angeles. Paper tape recordings at 1 min intervals were taken with a sensitivity of 0.1 μgal, during an interval of 4.6 days. Analysis of the data with an IBM 709 computer shows a frequency spectrum which agrees, in respect to the radial, or spheroidal modes, with the corresponding free periods of the Earth, computed by Pekeris. Dr. Press and I had an opportunity to compare the gravimeter and Benioff's strain-meter results yesterday. The degree of agreement (for the spheroidal modes) was indeed remarkable. The periods seldom depart in the two cases by more than 0.1 or 0.2 min. The following figures illustrate the degree of agreement between theory and the two completely independent types of observations. In magnitude, all the listed gravimeter spectral peaks are well above the 95 % confidence level.

Theory	53.7	35.5	25.7	20.0	13.6	11.9	8.67 min
Gravimeter	54.5	35.6	25.7	20.0	13.5	11.8	8.4 »
Strain-meter (Benioff)	53.3	35.6	25.8	19.9	13.5	11.8	8.4 »

Further information concerning the gravimeter results will be supplied in a paper scheduled for presentation at the 18th session (paper 96).

Prof. Pekeris : I was most impressed by one feature of the seismic and gravimetric records of the free oscillations of the Earth, reported by Press and Slichter respectively. The free torsional oscillations do not produce a variation in the gravitational field, in contrast to the spheroidal oscillations. The gravimeter should therefore not have recorded those free oscillations which are torsional, and this is actually the case. Had it been otherwise, the evidence for the reality of the free oscillations of the Earth had been less convincing.

11. — *Prof. James T. Wilson* presents the paper by *J. T. Wilson* and *D. E. Willis :* Frequency spectra of seismic waves generated by earthquakes and explosive blasts.

Seismic waves generated by natural, high explosive and nuclear sources were recorded on magnetic tape using low frequency (1 cps) seismometers. Spectral analyses were then made of these recordings by means of two different techniques. One method involves playing the recordings back through variable pass band filters, while the other entails digitalizing the broadband recording and performing a Fourier analysis using an electronic computer. A comparison of the results obtained using these two techniques, is presented and the spectra of the various waves are discussed as functions of source and distance.

This work was supported by the Office of Naval Research under Contract Nonr-1224 (33) and by Project MICHIGAN under Department of the Army Contract DA-36-039-SC-78801, administered by the U.S. Army Signal Corps.

12. — *Rev. Dr. Lynch, S. J.,* reads the paper by *H. F. Birkenhauer, S. J. :* Statistical studies of blasting vibrations.

Displacement, velocity and acceleration caused by quarry blasts may be measured by various instruments. Where a large group of data indicates considerable variability, it is still possible to test for consistency by the methods of industrial quality control. A sequence of blasts is analyzed as a pilot run, in which the measured amplitudes, velocities or accelerations are divided into groups of four or five. A minimum of twenty measurements for a given weight and distance is advised.

The average and range of each subgroup are computed and control chart limits are plotted. If all subgroup averages and ranges lie within these limits, we infer that the variation from blast to blast is due to chance causes. Under these conditions, it is possible to estimate the range over which the vibration parameter can be expected to vary. Sampling inspection, by which a percentage of the blasts is monitored, is sufficient as long as the process remains in control.

The techniques of statistical correlation can be used to estimate the strength of the relationship between two vibration parameters (e. g., displacement and acceleration) when more than one type of instrumentation is used.

This paper will not be submitted for publication. Recent papers by Rev. Dr. Birkenhauer, S.J., on these and related problems have been published in the *Earthquake Notes,* Vol. 25, No. 2, 1954, pp. 20-22 ; Vol. 26, Nos 3-4, 1955, pp. 21-22 ; Vol. 28, Nos 2-3, 1957, pp. 14-15 ; Vol. 30, No. 3, 1959, pp. 35-36 (together with M. V. Studer) ; Vol. 31, No 3, 1960, pp. 29-33 (together with R. J. Orr and T. J. Yule).

For certain time reasons, *Dr. Nanda* presents at the end of this session his two papers. They are included in the 10th and 11th sessions respectively, where they belong with regard to their content.

The session is closed at 12.25.

6th SESSION

WEDNESDAY, JULY 27 (afternoon)

Program

1. — Scientific communications : Rock Age Determinations ; cont.

This symposium was organised by CIGAR, with participation of IASPEI. So far, no decision has been reached concerning the publication of the proceedings of this symposium. A summary report has appeared in the *Geophysical Journal,* Vol. 3, No. 4, Dec. 1960, pp. 470-474.

7th SESSION

WEDNESDAY, JULY 27 (afternoon)

Program

2. — Necrologies.
3. — Report of the Secretary General (Prof. Rothé).
4. — Constitution of a Finance Committee.
5. — Report of the Director of the ISS (Dr. Stoneley).

6. — Discussion on ISS.
7. — Constitution of a Nomination Committee.
8. — Project of investigation of the upper mantle (Prof. Beloussov).
9. — The problem of publications.
10. — Seismological dictionary (Prof. Guyot).

The session is opened at 14.45 with *Sir Harold Jeffreys* in the chair.

2. — Necrologies.

President Sir Harold Jeffreys pays homage to the deceased scientists of our Association : *I. Bóbr-Modrakowa, T. N. Burke-Gaffney, S. J., R. A. Daly, G. A. Gamburtsev, B. Gutenberg, E. W. Janczewski, A. W. Lee, P. Molard, A. Rey Pastor, N. Shalem, H. E. Tatel, V. Vukojičić, H. O. Wood.* The assembly observes one minute of silence to their honour.

Irena Bóbr-Modrakowa (1889—1959).

On February 25, 1959, after 45 years of scientific activity, deceased dr. Bóbr-Modrakowa, Head of the Seismological Observatory of the Institute of Geophysics, P. A. Sces., for many years distinguished President of the Polish Society of Geophysics, member of the International Association of Seismology and Physics of the Earth's Interior and author of more than 20 scientific books and papers, among them 8 volumes of the Seismological Annual for 1940-1950.

I. Bóbr-Modrakowa was born in Lowicz on January 25, 1889, went to school in Warsaw and Petersburg, studied mathematico-physical sciences from 1908—1912, obtaining her diploma with highest marks in 1914. From 1914—1920 she was on the staff of the Seismological Commission of the Academy of Sciences at Petersburg, where she worked under the direction of the eminent seismologist Prof. B. B. Golicyn, publishing two papers in the Bulletins of the Commission. She also took part in the work of the Seismological Station at Pulkowo.

On her return to Warsaw in 1921, I. Bóbr-Modrakowa was nominated senior assistant of the Institute of Experimental Physics of Warsaw University, where in the years 1926—1927 she organized an X-ray laboratory. In 1928 she obtained the degree of D. Phil., her thesis dealing with "Investigation of photographic emulsions by X-rays". In the following year she took an active part in founding the Polish Society of Geophysicists, on behalf of which she undertook later on the preparatory work for the establishment of a seismological observatory in Warsaw. To this end she visited the major observatories in Belgium, France and Germany, studying there up-to-date observational methods and instruments. Due mainly to her efforts, the Seismological Observatory at Warsaw was established on January 1, 1939, Doc. Bóbr-Modrakowa being nominated head of the institution. The scientific work was interrupted by the outbreak of the war in September 1939, but renewed on January 1, 1940, after repair of damages caused by bombardment, the Observatory being the only department of Warsaw University which had remained relatively intact. Doc. I Bóbr-Modrakowa who alone had remained in charge of the Observatory, successfully opposed several attempts by the German occupation authorities to remove the equipment to Germany.

After the end of the war, the Observatory was reconstructed at the initiative of the State Institute of Geology with the very active cooperation of Dr. Bóbr-Modrakowa. On June 1, 1953, the Observatory was incorporated in the newly established Institute of Geophysics of the Polish Academy of Sciences, the direction remaining in the hands of its most active officer, Dr. Bóbr-Modrakowa, who worked on her post until her decease.

Dr. Irena Bóbr-Modrakowa was decorated with the Golden Cross of Merit and the Knights Cross of Poland Restored.

(This biography has been kindly supplied by Dr. R. Teisseyre).

Thomas Noel Burke-Gaffney, S. J. (1893—1958).

With the death of Thomas Noel Burke-Gaffney on September 14, 1958, Australian seismology has suffered an almost irreplaceable loss.

Father Burke-Gaffney became director of the Riverview College Observatory in 1952 when the former director, Father D. J. K. O'Connell, was appointed director of the Vatican Astronomical Observatory. He occupied the post with distinction, and more than maintained the reputation which Riverview has held for fifty years as one of the world's first-class seismological observatories.

He played a valued part in Australia's International Geophysical Year work as convener of the National Subcommittee on Seismology, and was for several years a member of the Council of the Royal Society of New South Wales. In these and related offices he gave of his best.

His published work includes seven papers on seismology, the last of which appeared in the *Australian Journal of Physics* shortly after his death. The papers were concerned with the seismicity of Australia, the problem of detecting S waves in the Earth's inner core, special phases from New Zealand earthquakes, and seismic aspects of nuclear explosions. The last work has attracted world-wide attention.

Father Burke-Gaffney was born in Dublin on December 26, 1893, and entered the Jesuit order in 1913. He took up residence in Australia in 1928 as senior science master at St. Ignatius's College, Riverview, Sydney, and in 1946 became assistant director of the College Observatory.

(This biography is a condensed version of the one given by Prof. Bullen in *Nature,* Vol. 182, No. 4646, 1958, pp. 1343-1344).

Reginald Aldworth Daly (1871—1957).

Reginald Aldworth Daly, Sturgis-Hooper Professor Emeritus in Geology at Harvard University, died September 19, 1957, at the age of 86. He was born at Napanee, Ontario, took his baccalaureate degree from the University of Toronto in 1891, his master's degree from Harvard in 1893, and his doctorate in 1896. He studied at the University of Heidelberg and the Sorbonne. He was the recipient of a number of honorary doctorates and a member of the National Academy of Sciences. He was a recognized international authority on various geological subjects, especially those relating to structural geology. He was one of the original members of the American Geophysical Union, and in 1946 was designated as the Eighth Recipient of the William Bowie Medal.

Prof. Daly began his career with broad field study and mapping in difficult terrane. Throughout a busy life, he has exhibited two outstanding passions : to bring together as many geologic facts as possible, and to fashion from these facts clues to the geologic processes and to the complicated history of the Earth. He early mastered petrography, as a means of deciphering the origins of rock masses. He delved especially into the complexities of igneous bodies, to learn the messages they have brought from the depths. He has not been concerned with merely descriptive, geometric study ; his viewpoint is emphatically that of dynamics, with the object of discovering the deforming forces and their ultimate origin. His incursions into broad geomorphic fields — involving coral reefs, strandlines, features of glaciated regions, submarine valleys — have had the same incentive of prying into the innermost secrets of Earth-dynamics.

(This biography has the following sources : *Trans. Amer. Geophys. Union,* Vol. 27, no. 4, 1946, pp. 457-458, and Vol. 39, No. 1, 1958, p. 144).

G. A. Gamburtsev (1903—1955).

G. A. Gamburtsev was born in 1903 in St. Petersburg. In 1926 he finished his studies at the physical-mathematical faculty of Moscow university. His first research works began in 1925. He then studied the magnetic anomaly of Kursk and also used gravimetric and seismic prospecting methods. Later he worked on the perfection of seismic methods (reflexion method, correlation method, high frequency seismic methods, deep sounding methods, etc.). Gamburtsev has contributed considerably to the development of modern seismic methods. He has investigated electromechanical systems and developed the method of electromechanical analogies. The method he developed for deep seismic soundings made it possible to investigate the structure of the Earth's crust down to several tens of kilometers. Under his direction a number of geophysical observatories were established. In 1946 he was made corresponding member and in 1953 ordinary member of the Academy of Sciences of the U.S.S.R. From 1946 to his death he was director of the Geophysical Institute of the Academy of Sciences.

(This is an abstract of a paper by Prof. Y. V. Riznichenko, The life and work of G. A. Gamburtsev (in Russian), *Bull. Sov. po Seism.,* AN SSSR, Vol. 3, 1957, pp. 5-10 ; Russian abstract in *Ref. Z. Geofiz.,* Vol. 12, 1958, No. 8603).

Beno Gutenberg (1889—1960).

Professor Beno Gutenberg, world-renowned specialist in seismology and other aspects of geophysics, died January 25, 1960. He was born in Darmstadt, Germany, June 4, 1889. He received his Ph. D. at Göttingen in 1911 and began his research work in seismology at the Bureau Central in Strasbourg under the direction of Professor Hecker. After having an academic post at Frankfurt/Main for a few years, he left Germany in 1930 and became professor of geophysics at the California Institute of Technology, Pasadena, a post from which he retired in 1959. From 1947 to 1957 he was director of the Seismological Laboratory at Pasadena. He took an active part in the work of our association and was its president 1951—1954.

Professor Beno Gutenberg's contributions in seismology unquestionably qualify him for the title of Dean of Modern Seismology. They began prior to World War I and have continued up to the time of his death. He has worked on every significant problem concerning the physics of the earth's interior, as well as having made contributions in meteorology and atmospheric physics. There is hardly a single paper in physics of the earth's interior which does not refer to his work. His many awards and honorary degrees were justifiably earned.

A few of his many outstanding contributions are :

1. The precise determination of the depth of the earth's core.
2. Determination of the travel times of seismic waves.
3. Studies on the seismic geography of the world.
4. Techniques for evaluating the magnitude and energy of earthquakes.
5. The temperature and physical properties within the earth as a function of depth.
6. Structure of the earth's crust and outer mantle.
7. Mechanism of earthquakes .
8. Microseisms.

Professor Gutenberg has published several hundred papers, including 7 books. His most recent work was published only a few weeks before his death. Although he retired in 1959, he prosecuted his research vigorously almost up to the time of his passing.

It can be truly said that Professor Gutenberg will be missed by his colleagues and friends. He was a noble man, kind, gentle, whose main purpose in life was to search for scientific truth. He influenced many geophysicists, who will always be indebted to him for his inspiration and his selfless efforts on their behalf. His warm and gentle personality will be remembered by all of us.

(The latter part of this biography, relating to Professor Gutenberg's scientific works, has been kindly supplied by Prof. Press).

Edward Walery Janczewski (1887—1959).

On August 24, 1959, the eminent Polish geophysicist E. W. Janczewski died, in Cracow, professor of the Academy of Mines, Chair of Applied Geophysics. Born in Cracow in 1887, he studied geophysics and geology at the Jagellonian University, subsequently in Switzerland and France. On his return to Poland he worked at the State Geological Institute in Warsaw as chief geophysicist until 1939. In this period he organized geophysical exploration work in Poland by means of gravimetric, magnetic, seismic and electrical methods, making thereby an essential contribution to the knowledge of the geological structure of this country. After World War II E. W. Janczewski was called to the chair of applied geophysics at the Academy of Mines which he held until his death. Here he educated a great number of Polish engineers — geophysicists who at present are active in various institutes and geophysical exploration organizations. E. W. Janczewski is the author of numerous scientific papers and several textbooks on applied geophysics.

(This biography is a summary of one which appeared in *Acta Geophysica Polonica,* Vol. 8, No. 1, 1960, pp. 36-40).

Alwyn Walter Lee (1899—1956).

Dr. Alwyn Walter Lee, seismologist and meteorologist, died on 10th February 1956 aged 57 years. He studied meteorology at the Imperial College of Science and Technology, London, under Sir Napier Shaw, and joined the staff of the Meteorological Office, London, in 1923. After five years' spell of duty at Lerwick, in the Shetland Islands, he was transferred to Kew Observatory in 1929.

At Kew, under the Directorship of Dr. F. J. W. Whipple, he devoted himself to seismology, with notable success. During this time he made a "special study" of the Baffin Bay earthquake of 1933, November 20, and compiled a Geophysical Memoir on the travel of P and S. It was, however, in connexion with microseisms that his meteorological training proved specially valuable: recognising that microseisms recorded at seven stations in Great Britain appeared to be Rayleigh waves, in which the motion of the surface particles is retrograde, he extended his investigation to include the records of microseismic activity at some 60 stations in all parts of the world. He thus was able to discuss the direction of the approach of microseisms in relation to the synoptic charts of low pressure centres over the Atlantic Ocean and Western Europe, and concluded that the current view of the genesis of microseisms by atmospheric depressions was inadequate. By using the theory of the propagation of Rayleigh waves in a surface layer he inferred the relation between the ratio of the vertical and horizontal amplitudes of microseisms and the nature of the general rock formation across which they were travelling. In 1938 he produced a valuable treatise on "Earthquakes and Other Earth Movements"; this was based on the book, under the same title, by John Milne, but was so completely revised and re-written that it was in effect a new and up-to-date exposition of a science that had greatly developed since the days of Milne's pioneer researches.

With outbreak of World War II Lee reverted to meteorology, and after a short period of duty at the headquarters of the Meteorological Office in London, became, in June 1940, Senior Meteorological Officer to No. 12 Fighter Group, Royal Air Force. After the war he came back to the Air Ministry in London, but in 1947 experienced a serious breakdown in health. However, he was able to continue with seismological work at Kew until his retirement in 1954. It is sad indeed to record the passing of so able and devoted a seismologist.

(This biography has been kindly supplied by Dr. R. Stoneley).

Pierre Molard (1911—1959).

Pierre Molard was born in 1911 at Issy-l'Evêque (Saône-et-Loire), France. In 1936 he began his work at the Observatory of Martinique, under the direction of A. Romer. P. Molard installed the station of Morne-des-Cadets, mainly for the purpose of geophysical observations of the volcanic activity of Mount Pelée, situated 7 km from the station. He installed there a 20 ton De Quervain-Piccard seismograph. Since 1947 the Observatory of Martinique, then under the direction of P. Molard, was attached to Institut de Physique du Globe in Paris. In the following years, an auxiliary station was installed at Guadeloupe.

Since 1940, P. Molard carried through a research program in meteorology, atmospheric electricity, and seismology. He constructed seismographs, specially adapted for their particular use at the observatory, i.e. the supervision of the volcanic activity and the study of microseisms as a method to discover tropical cyclones. His main contribution in this respect is his construction of seismographs with electronic amplification, using the variation of the frequency of an oscillating circuit, as function of the capacity. The seismographs at Martinique and at Guadeloupe are based on this principle. P. Molard has also studied the T phases recorded at his stations.

Alphonse Rey Pastor (1890—1959).

Alphonse Rey Pastor was born February 16, 1890, at Burgos, Spain. He had mainly a military education, but went to the University in Saragosse to study spherical astronomy and geodesy and became a geographical engineer in 1920. Soon afterwards he came to the Observatory of Toledo, where he collaborated with Mr. Vicente Inglada Ors. He improved the seismographs of the observatory and invented a seismograph with independent components. He devoted himself to fruitful seismological research, and one of his publications, « Traits Séismiques de la Péninsule Ibérique », is of fundamental importance for all other studies on the seismicity and the seismotectonics of the Iberian Peninsula. He also created the Central Geophysical Observatory of Buenavista.

After the Civil War he moved to the Observatory of Alicante, where he continued his work and published a number of papers on the tectonics and the seismicity of the region of Murcia and Alicante. He made a card file of all Iberian earthquakes. He also improved the instrumentation at Alicante. He died September 28, 1959.

(This biography is an abbreviated version of the one kindly supplied by Ing. Bonelli-Rubio).

Nathan Shalem (1897—1959).

Dr. Nathan Shalem was born in Saloniki in 1897. In 1924, he went to Florence, where he studied natural sciences, particularly geology, and received his doctor's degree. Later he spent several years studying geography at the University of London. After several years' activity as a teacher, he joined the Geological Survey of Israel in

1954 as Head of the newly formed Department of Quaternary Geology and Geomorphology. He died in Jerusalem on September 19, 1959.

Dr. Shalem's scientific interests were broad and manifold, for he set himself the task to study natural phenomena in all their aspects and interrelationships. His first pioneering work was on the geology of the Judean Mountains. For many years he worked in the Judean Desert, which he studied in all its aspects. His many studies, published in numerous papers in Israel and abroad, were devoted to subjects as varied as palaeontology, volcanology, oceanography, gemology, and speleology. His last manuscript, completed just before his death, deals with the salt caves of Mount Sdom. He also transgressed into fields of prehistory, geography, and even Palestinian folklore.

Dr. Shalem's particular enthusiasm, however, was devoted to seismology. He built up a network comprising many hundreds of voluntary observers all over Israel, from professional scientists to farmers and bus drivers. The many completed questionnaires received at the Geological Survey after each earthquake in the country constitute one of the best organised and most thorough systems of seismic observation anywhere in the world. Combining his scientific and historical interests, Shalem compiled an as yet unpublished survey of all earthquakes in the Middle East described or mentioned since biblical times. His published works in the field of seismology comprise macroseismic maps of all the major earthquakes of the Middle East during the last fifteen years, as well as papers dealing with the relationship between seismic and tectonic features of the Middle East and tsunamis of the Mediterranean.

(This is an abbreviated version of a biography by Y. K. Bentor, *Bull. Res. Council of Israel,* Vol. 9 G, 1960).

Howard Edwin Tatel (1914-1957).

Dr. H. E. Tatel, Research Physicist of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, died November 15, 1957, at the age of 43. He was born in New York, and took his baccalaureate degree from Massachusetts Institute of Technology in 1935, his master's degree in 1936, and his doctorate from Stanford under a Rosenberg Science Fellowship in 1940. He did research work in physics at the University of Michigan, worked with the Carnegie Institution of Washington from 1941 to 1943, and with the Applied Physics Laboratory of Johns Hopkins University from 1943 to 1947. In 1947, he returned to the Carnegie Institution where he continued until the time of his death. Only a short time before his death, he had returned from a scientific expedition in Bolivia and the Highlands of the Andes on work connected with the International Geophysical Year.

Dr. Tatel is mostly known for his contributions in the seismic expeditions of the Carnegie Institution for the determination of crustal structure, both in North and South America.

(The main part of this biography, first paragraph, is copied from *Trans. Amer. Geophys. Union,* Vol. 39, No. 1, 1958, p. 144).

Voislav Vukojičić (1914-1960).

Professor V. Vukojičić was born December 6, 1914, at Jabliak, Montenegro, and died in Belgrade January 16, 1960. After having spent several years with the organisation both of the school system and later of the scientific institutions in Yugoslavia, he joined the Seismological Institute of Belgrade in 1950 as an associate director. After the death of Professor J. Mihailović in 1956, Professor Vukojičić became director of the institute. He represented Yugoslavia in the European Seismological Commission.

(This is an abbreviated version of a biography kindly supplied by Mr. D. N. Trajić).

Harry Oscar Wood (1879-1958).

Harry Oscar Wood was born at Gardiner, Maine, New England, on July 28, 1879. His advanced education was completed at Harvard in 1904. From 1904 to 1912 he was instructor in mineralogy and geology at the University of California at Berkeley. Originally a geologist, his seismological interests were waked by the San Francisco earthquake of April 18, 1906, of which he was a witness. Wood was charged with the work of investigating the extent and nature of damage in the city of San Francisco. The earthquake led eventually to the founding in 1911 of the Seismological Society of America, of which Wood was a member from the beginning and in which he later served in various capacities. From 1912 to 1917 Wood was a research associate at the Hawaiian Volcano Observatory, which gave him opportunity to apply his interests both in petrology and seismology.

In 1916 Wood published a detailed plan for a seismic network of stations in Southern California, which subsequently led to the founding of the Seismological Laboratory in Pasadena. Wood's experience and his study of the literature convinced him that conventional seismographs, with long-period characteristics and timing good only to about one second, were not adequate for local earthquake problems. Together with Dr. J. A. Anderson of the Mt. Wilson Observatory he developed the Wood-Anderson torsion seismometer, of which the first was constructed in 1922. Wood was Director of the Laboratory from the start in 1927 up to 1947.

H. O. Wood has published over 60 papers, mainly in seismology and a few in volcanology and petrology. His activity in the last twenty years was greatly diminished due to illnesses. He died in Pasadena on February 4, 1958.

(This is an abbreviated version of the biography published by Prof. C. F. Richter in *Proc. Vol. Geol. Soc. Amer.*, Ann. Report 1958, 1959, pp. 219-224).

3. — Report of the Secretary General.

The Secretary General, *Professor Rothé,* presents his report :

Mes chers Collègues,

Les trois années qui viennent de s'écouler peuvent être placées sous le signe des grandes entreprises de collaboration internationale que furent l'A.G.I. et la Coopération Géophysique Internationale 1959.

Des documents de plus en plus nombreux ont été rassemblés ; le travail du Secrétariat de l'Association et surtout du Bureau central s'en est trouvé très fortement augmenté. Nous y reviendrons tout à l'heure.

Le Secrétariat de l'Association a préparé le volume des Comptes Rendus de l'Assemblée de Toronto. Notre secrétaire général associé Markus Båth est venu à Strasbourg préparer avec moi le travail, puis il en a assuré la rédaction. Pour des raisons d'économie l'impression a été faite comme d'habitude à Strasbourg. Le prix de la publication a légèrement dépassé 1 million de francs anciens (soit l'équivalent de 2 000 dollars). L'UNESCO nous a accordé pour cette impression une subvention de 550 dollars. Le volume est présenté exactement comme le précédent ; la liste des personnalités intéressées à la Séismologie a été remise à jour après une enquête faite par M. Båth; de nombreux rapports nationaux ont été publiés dont une partie avait été fournie déjà imprimée par les soins des comités nationaux dans le format de nos Comptes Rendus. Ce volume contient les rapports nationaux des différents pays et j'estime que ce volume fournit une image intéressante de l'activité séismologique dans le monde pendant la période qui a précédé l'Assemblée de Toronto. Des exemplaires de ce volume sont encore disponibles; ceux de nos collègues qui désireraient en recevoir voudront bien en aviser le Secrétariat de l'Association.

Une autre publication importante a été celle du volume contenant une partie des mémoires présentés au cours de l'Assemblée de Toronto : ce volume constitue le fascicule 20 des Publications Scientifiques de notre Association: il comporte 442 pages (contre 408 pages pour le fascicule 19) se rapportant à 38 communications. Son impression a coûté 1.992.000 francs soit environ 4000 dollars (à noter que l'UNESCO nous a accordé une subvention de 1470 dollars pour cette publication).

Vous voyez que le chapitre publications, déductions faites des subventions de l'UNESCO, représente pour l'Association une dépense d'environ 2 millions de francs, c'est-à-dire environ 28 % des dépenses totales de l'Association (dépenses totales en France : 6.211.553 F., dépenses en Angleterre : subventions à l'I.S.S. : 800 £ soit 1.100.000 F.).

Je vous donnerai maintenant rapidement un aperçu sur le travail effectué au Bureau central séismologique de Strasbourg et sur la préparation du Bulletin mensuel, l'un des services de la Fédération des services permanents de l'ICSU.

Le Bureau central International de Séismologie assure la coordination dans l'échange des données des différentes stations séismologiques, coordination indispensable pour l'étude générale de la séismicité du globe et pour l'étude particulière de chacun des grands séismes.

Depuis le début de l'Année Géophysique Internationale, le Bureau central International de Séismologie de Strasbourg est devenu Centre Mondial C. Ainsi sont concentrés à Strasbourg les bulletins provisoires, télégrammes, cartes et lettres-avion envoyés par la quasi-totalité des observatoires séismologiques du monde entier.

Préparation du bulletin.

Depuis le début de l'Année Géophysique et en raison de l'augmentation considérable du nombre de données reçues, les dépouillements extraits des bulletins et des autres documents sont mis sur fiches, ce qui permet un classement chronologique rapide par date, heure, minute, seconde ; les données correspondant aux enregistrements d'un même séisme sont groupées, une détermination d'épicentre est tentée, en général par l'emploi de la méthode des hyperboles tracées d'après les différences des temps d'arrivée des ondes P dans des couples de stations réparties aussi régulièrement que possible autour de l'épicentre présumé. Les distances de l'épicentre à un grand nombre de stations sont mesurées sur un globe de 80 cm de diamètre ; l'heure origine du séisme est contrôlée et les phases indiquées sont éventuellement rectifiées. Des observations macroséismiques sont utilisées chaque fois que cela est possible : à noter que ces observations macroséismiques restent souvent très utiles pour la détermination précise des épicentres.

Le travail est effectué sous le contrôle personnel du Professeur Rothé, Secrétaire général de l'Association internationale de Séismologie et de Physique de l'Intérieur de la Terre ; deux assistants techniques, MM. Marzi et Perret, participent au travail ; la rédaction des fiches a été confiée à des auxiliaires, étudiants géophysiciens.

Comme les années précédentes, le bulletin a été imprimé en Vari-Typer : l'impression et le tirage est entièrement exécuté par le personnel de l'Institut de Physique du Globe de Strasbourg dont il convient de souligner, par conséquent, la part prise dans la préparation du Bulletin.

Trois cents observatoires séismologiques reçoivent régulièrement ce bulletin qui constitue un document de base pour la préparation des bulletins définitifs et pour le choix des études spéciales à entreprendre sur des séismes particuliers.

Documentation statistique.

Depuis l'ouverture de l'Année Géophysique, le bulletin contient *toutes* les données reçues au Centre Mondial C de Strasbourg : le classement et la publication de ces données représentent par conséquent une participation importante au travail de l'Année Géophysique Internationale. L'étude du bulletin fournit immédiatement un aperçu précis de l'activité séismique en chaque point du Globe ; cette activité séismique se rapporte, non seulement aux séismes les plus importants, mais encore aux séismes plus faibles inscrits isolément ou dans deux ou trois stations seulement.

Le tableau suivant contient quelques données statistiques relatives au bulletin. Le nombre de pages publiées a progressé de façon considérable. 938 en 1957, 1538 en 1958, 2002 en 1959. Ces seuls chiffres montrent quel est l'effort qu'a dû fournir le personnel trop réduit du Bureau pour assurer régulièrement la publication.

Publication en 1957

Mois	Pages	Séismes étudiés	Epicentres déterminés	Régions indiquées	Séismes indéterminés
Août 1956	70	141	112	21	8
Septembre	66	157	102	30	25
Octobre	83	233	126	50	57
Novembre	68	176	114	39	23
Décembre	79	150	114	26	10
Janvier 1957	77	160	125	30	5
Février	76	157	122	26	9
Mars	256	420	340	58	22
Avril	163	346	211	99	36
	938	1940	1366	379	195

Publication en 1958

Mai 1957	121	269	165	72	32
Juin	118	254	139	77	38
Juillet	172	254	175	62	17
Août	164	294	203	64	27
Septembre	155	227	173	36	18
Octobre	171	258	211	37	10
Novembre	151	201	174	21	6
Décembre	160	203	163	29	11
Janvier 1958	162	185	152	27	6
Février	164	210	177	27	6
	1538	2355	1732	452	171

Publication en 1959

Mars 1958	160	229	186	30	13
Avril	216	298	232	36	30
Mai	204	308	237	46	25
Juin	194	257	192	40	25
Juillet	210	304	235	43	26
Août	212	309	260	30	19
Septembre	168	187	151	23	13
Octobre	183	279	204	44	31
Novembre	269	426	297	106	23
Décembre	186	293	200	63	30
	2002	2890	2194	461	235

L'accumulation des données a entraîné un retard dans la parution, retard regrettable, qui cependant permet de publier un bulletin plus complet, certaines données ne nous parvenant qu'avec un long délai. Au moment où je vous parle le bulletin de juillet 1959 est achevé et les manuscrits des bulletins d'août et septembre 1959 sont prêts.

Ainsi que je le disais tout à l'heure nous avons depuis le bulletin de juillet 1957 inclus dans le bulletin toutes les données reçues. Pendant les six premiers mois de l'AGI (juillet-décembre 1957) 50.720 dépouillements d'inscriptions ont été étudiés ; ce nombre a atteint *114.982* pour l'ensemble de l'année 1958. C'est la première fois qu'une telle documentation est recueillie et publiée.

Statistique concernant l'activité séismique pendant l'année géophysique juillet 1957 — décembre 1958.

Il est, je crois, intéressant de voir comment les données recueillies se répartissent en fonction du nombre de stations ayant enregistré un séisme déterminé.

Nombre de stations ayant inscrit le séisme	Nombre de séismes juillet 1957-déc. 1958		Nombre de données		Pourcentages	
	1957 (six mois)	1958 (douze mois)	1957 (six mois)	1958 (douze mois)	1957	1958
1	9.440	23.106	9.440	23.106	18,6	20,1
2 à 5	2.049	4.719	5.713	12.940	11,3	11,2
6 à 10	423	919	3.240	6.969	6,4	6,1
11 à 20	294	640	4.362	9.477	8,6	8,3
21 à 30	133	309	3.353	7.739	6,6	6,7
31 à 40	88	171	3.105	6.071	6,1	5,3
> 40	255	564	21.107	48.680	42,4	42,3
	12.682	30.428	50.720	114.982	100,0	100,0

Pour les deux périodes considérées on remarquera le nombre important de séismes inscrits en une seule station, ce qui montre que le nombre de stations séismologiques permanentes est encore insuffisant pour l'étude détaillée des faibles séismes et en particulier pour en déterminer les épicentres ; or, les récentes recherches montrent que cette étude peut présenter un grand intérêt pour le problème de la prévision des grands séismes.

Par contre près de la moitié des données publiées se rapporte aux séismes inscrits dans plus de 30 stations.

Les deux dernières colonnes du tableau permettent de comparer le pourcentage des données réparties par groupe, d'une part pour 1958, et d'autre part pour les six derniers mois de 1957. On remarquera que, au cours de ces deux périodes, l'activité séismique présente exactement les mêmes caractères statistiques.

Déterminations rapides d'épicentres.

Conformément au vœu formulé à Stuttgart en 1952 par la Commission Séismologique Européenne nous avons continué à effectuer des déterminations rapides d'épicentres pour les séismes originaires d'une zone située à moins de 5.000 km du centre de l'Europe. Ces déterminations sont aussi précises que possible et s'appuient sur les premiers renseignements macroséismiques qui ont pu être communiqués. Comme je vous le disais il y a trois ans ces déterminations rapides résultent des données que nous font parvenir rapidement nos collègues européens ou d'Afrique du Nord ; je les remercie vivement de leur collaboration, collaboration indispensable pour le travail séismologique. 26 déterminations ont été diffusées en 1957, 25 en 1958, 38 en 1959.

Les dépenses du Service Permanent du bulletin mensuel se sont naturellement accrues en même temps que le nombre de données étudiées augmentait : du personnel supplémentaire a dû être engagé, les frais d'impression et d'envoi ont été plus élevés.

1957 :	1.369.670
1958 :	2.138.078
1959 :	2.602.231

Total : 6.109.979 (contre 3.247.631 francs pour la période 1954—1956).

Pendant cette même période et grâce aux efforts du secrétaire général de l'Union, M. Laclavère, auquel je tiens à adresser de bien vifs remerciements, l'UNESCO nous a accordé une subvention totale de 8450 dollars, soit 3.575.205 francs ; il est donc resté à la charge de l'Association une dépense de 2.534.774 francs, ce qui représente par conséquent 35% des dépenses totales.

L'International Seismological Summary constitue l'un des autres services permanents intégrés dans la Fédération des services permanents de l'Union. Vous entendrez dans un instant le rapport du Docteur Stoneley. J'indiquerai ici que le Bureau de Strasbourg a continué à établir des fiches de renseignements macroséismiques avec éventuellement l'indication de l'épicentre macroséismique, fiches qui ont été envoyées à Kew pour être utilisées pour le service de l'I.S.S. Un fichier en double est conservé à Strasbourg.

L'Association a participé à la gestion de l'I.S.S. par une subvention de 800 livres, soit 1.100.016 francs (15% des dépenses totales). 400 autres livres se rapportant à l'exercice 1959 ont dû être prélevées au cours de l'année 1960.

Il convient de rappeler ici l'effort fait par l'UNESCO en faveur de l'I.S.S., effort qui s'est monté à 3000 dollars en 1957, 4400 dollars en 1958 et 4500 dollars en 1959, soit au total 11.900 dollars (soit 5.121.000 francs).

Telles sont les principales dépenses effectuées par notre Association avec le concours de l'UNESCO. Ajoutons que les frais de secrétariat, poste, etc... se sont élevés à 1.620.336 francs soit 22% du total des dépenses.

Il convient encore de dire quelques mots de l'activité de la Commission Séismologique Européenne. Celle-ci s'est réunie à Utrecht du 8 au 12 avril 1958 et à Alicante du 27 au 31 octobre 1959. Ces deux réunions ont pu être organisées grâce à des subventions accordées par l'UNESCO (750 dollars en 1958, 2000 dollars en 1959).

Les comptes rendus de la réunion d'Utrecht ont été publiés par les soins du secrétariat général de l'Union. Ceux de la réunion d'Alicante sont en préparation et doivent constituer la monographie n° 6 de l'UGGI.

Le Bureau de la Commission Séismologique Européenne, élu à Alicante, comprend nos collègues Bonelli, président, Savarensky et Zátopek, vice-présidents, et Peterschmitt, secrétaire.

Parmi les autres réunions qui se sont tenues depuis 1957 il faut signaler la réunion du CSAGI à Moscou en août 1958 au cours de laquelle d'importantes décisions reproduites dans notre bulletin mensuel ont été prises.

Mentionnons également la réunion organisée à Messine en décembre 1958 consacrée à l'étude des problèmes de génie séismique, réunion à laquelle votre secrétaire général avait été invité à participer. Je pense que nous, séismologues, ne devons pas éviter les contacts avec nos collègues ingénieurs ou architectes qui s'occupent de constructions aséismiques. C'est bien à nous séismologues qu'il revient de définir les zones dangereuses au point de vue de leur séismicité et d'indiquer ces zones soit aux autorités gouvernementales soit directement aux ingénieurs et aux architectes.

Regardons maintenant un instant vers l'avenir. Il est indiscutable — et le nombre des participants de cette assemblée générale en est le témoignage — que la séismologie est actuellement en plein développement. Je voudrais ici pour terminer parler très brièvement de deux projets qui intéressent directement le développement de notre science.

Un premier projet émane de l'UNESCO : à la suite des séismes catastrophiques du printemps de cette année, l'UNESCO a demandé au secrétariat général de l'UGGI de préparer un rapport sur les besoins actuels de la séismologie. M. Laclavère est venu à Strasbourg en discuter avec moi et a remis il y a quelques semaines à l'UNESCO un rapport de documentation et un plan de travail.

Il est évident que si la prévision des séismes ne peut encore être réalisée, la protection des populations menacées par les séismes intéresse au plus haut point l'UNESCO. Nous avons donc proposé à la fois un but pratique mais aussi un développement de la séismologie théorique, car il est bien certain que c'est du développement des recherches théoriques que naissent un jour les applications pratiques.

L'UNESCO étudie actuellement ce plan et se propose de réunir sans doute l'année prochaine un comité d'experts.

Un autre projet intéressant est celui proposé par nos collègues américains. Je voudrais seulement l'évoquer très rapidement, M. Murphy ayant l'intention de s'en entretenir avec nos collègues et de présenter ultérieurement devant l'Association un projet détaillé. Il s'agit de créer sous les auspices de l'U.S.C.G.S. un réseau mondial de stations munies d'un appareillage standard, l'U.S.C.G.S. se chargeant de concentrer les dépouillements et d'en assurer l'interprétation.

Nous aurons sans doute l'occasion de revenir sur cette question dans une séance ultérieure, car il est bon, je pense, que notre assemblée générale puisse donner son avis sur un plan qui intéresse au premier chef notre organisation de collaboration internationale.

C'est par l'évocation de ces projets fort importants pour le développement de notre science que j'achèverai mon rapport.

APPENDIX

INTERNATIONAL ASSOCIATION OF SEISMOLOGY AND THE PHYSICS OF THE EARTH'S INTERIOR

Abstract of accounts for the period : 1 Jan 1957—31 Dec 1959

1	Amounts in Fr. Français (Anciens Francs)	Exchange rates : 1 dollar :	350 Fr. janvier-juillet 1957 420 Fr. juillet 1957 — décembre 1958 494 Fr. 1959
	Receipts	*IUGG*	*Grants & Contracts*
2	*IUGG Allocations*	5.245.440	
3	*UNESCO Grants*		
4	Organizational Expenses		0
5	Publications		1.309.180
6	Meetings of Committees		0
7	Symposia		1.303.000
8	Permanent Services		8.696.205
9	*Other Grants*		0
10	*Contracts*		0
11	*Sales of Publications*	232.127	
12	*Miscellaneous* (1)	400.044	
13	*Total Receipts*	5.877.611	11.308.385
	Expenditures		
14	*Secretariat*		
15	Personnel	642.754	
16	Quarters (rent, lights, heat, etc.)	6.607	
17	Supplies and equipment	257.987	
18	Postage, telegrams, telephone	251.330	
19	Travel (except for Assemblies and Symposia)	98.798	
20	Miscellaneous	870	
21	*Publications*		
22	C.R. Assemblies	797.446	231.000
23	C.R. Symposia	0	0
24	Periodicals	1.293.038	726.180
25	Others	199.792	105.000
26	*Assembly*		
27	Organization	121.580	0
28	Travel	0	0
29	*Symposia*		
30	Organization	6.557	0
31	Travel	0	1.303.000
32	*Scientific meetings*	0	0
33	*Subventions to Permanent Services, etc.*	3.634.790	8.696.205
34	*Contracts*		0

(1) dont : remboursement de tirés à part : 180.046
intérêts et dons : 219.998

		IUGG	Grants & Contracts
35	*Miscellaneous*	0	0
36	*Total Expenditures*	7.311.549	11.061.385
37	*Balance on hand* 1 Jan. 1957	4.443.663	
38	*Total Receipts*	5.877.611	11.308.385
39	*Plus value changes*	1.316.406	
40	*Total*	11.637.680	11.308.385
41	*Total Expenditures*	7.311.549	11.061.385
42	*Accounts payable*	0	247.000(2)
43	*Balance on hand* 31 Dec. 1959	4.326.131	0
44	*Total*	11.637.680	11.308.385

(2) C. R. Symposium Alicante non encore payés.

Détail des Bilans

1er janvier 1957

Strasbourg :	1.153.003	soit	1.153.003 Francs
Cambridge :	1675-2-3		1.641.500
Pasadena :	4711,89		1.649.160
			4.443.663

soit 12.700 dollars

31 décembre 1959

Strasbourg :	1.128.409	soit	1.128.409 Francs
Cambridge :	475-12-1		652.575
Pasadena :	5152,12		2.545.147
			4.326.131

soit 8.750 dollars

N.B. L'avoir de l'Association a diminué de 4.000 dollars au cours de la période 1957-1959.

Dr. Stoneley expresses the admiration and thanks of the members of the Association for the General Secretary's work. He emphasizes the close cooperation which exists between Strasbourg (BCIS) and Kew (ISS).

4. — Constitution of a Finance Committee.

A committee of three members is elected to check the accounts of the Association : *Ing. Bonelli-Rubio, Prof. Byerly,* and *Dr. Hodgson.*

5. — Report of the Director of the I.S.S.

The Hon. Director of the ISS, *Dr. R. Stoneley,* presents his report for the triennium 1957-1960 :

Accomodation and Staff. The work of the I.S.S. is carried out in offices at Kew Observatory, Richmond, Surrey, England, provided free of charge by the Director General of the Meteorological Office of the United Kingdom. By the courtesy of the Director of Kew Observatory, administrative help in connexion with payments to the I.S.S. staff is given by a member of the Observatory Staff.

The present staff consists of the following : Dr. R. Stoneley, Hon. Director, J. S. Hughes, M. A., Asst. Director, Mrs I. E. Sanders, J. H. Wavish, B. Sc., H. J. Gulley, G. A. C. Muir, B. Sc., as well as some part-time workers.

Material and Publication. In the past three years twelve quarterly numbers of the I.S.S. have been published, the latest being for the second quarter of 1952. With the extra staff that has been engaged it was expected that there would be a substantial overtaking of arrears of preparation. In fact, the large extra effort has been absorbed in coping with the enormous increase in the volume of material received from the stations. Some delay, too, was caused by the printing strike. In the triennium, 2829 epicentres were determined and 3248 pages of the Summary published. The high quality of the typography has been maintained. The rise in the number of pages published per annum is illustrated by the following table :

Year	'44,	'45,	'46,	'47,	'48,	'49,	'50,	'51
Pages	358	422	602	560	710	800	1081	1121

Thus, the volume for 1951 is double the size of that for 1947 ; the indications are that this increase will continue. In an attempt to economise in listing and in proof-reading I have recently begun to omit the « Additional Readings » and the lists of data for which no well-defined epicentre is indicated ; the discontinuance of the Additional Readings will be regretted by seismologists, but in any search for new phases or phases not well established recourse may be had to the readings already published for many years.

Finance. The income during the triennium has amounted to £2,000 per annum from the British Treasury, £400 p.a. from I.A.S.P.E.I., 1,000 Canadian dollars p.a. from the Canadian Government, and 4,400, 4,500, 7,250 U.S. dollars allocated by F.A.G.S. in successive years. For these subventions I wish to express the gratitude of seismologists. The size and the uncertainty of the income in any one year have prevented a more extended effort to overtake arrears, and a provisional extra allocation by F.A.G.S., conditional on arrears being overtaken in three years, could not be taken up because of the great increase in the readings received from stations. It will be recalled that in 1957 the Association asked that an annual sum of 10,000 U.S. dollars should be provided from international funds. It must be emphasised that there must always be a substantial balance in hand, since there is no way of guaranteeing a bank overdraft ; for instance, last December I had to hold-up temporarily a large account for printing, simply because the bank balance was exhausted.

The amounts spent on printing and salaries in 1957, 58, 59 were £8,985 and £4,694 respectively. Other expenses are relatively small. In the near future a revised catalogue of stations will be needed : this will call for a special subvention in order to provide for extra clerical assistance and computation. It is expected that a considerable part of this cost can be met from a grant from the funds of the British

Association Committee for Seismological Investigations. The increasing cost of production raises once again the desirability of making a substantial charge for the I.S.S.

The Future of the I.S.S. It seems to be the unanimously expressed desire of seismologists that the definitive calculation and publication of epicentres shall continue. Further, seismologists would like more information rather than less. The problem of the increase in the amount of observational material has however become acute. Over and above what we will call the « regular growth » of stations there will be (a) the observations begun during the I.G.Y. and continued as I.G.C. (b) the new stations and the re-equipped stations under the world-wide programme of seismological development financed by U.S.A. (c) the special stations set up under any scheme of « international inspection ». Whether or not (c) ever comes into being, it is clear that from about 1961 onwards the problem of utilising all the available seismological data will be of a greater order of magnitude than hitherto and the expense correspondingly great. The regular growth, too, will be accelerated if stations can be set-up on the sea floor.

Accordingly I recommend :

I. That the reductions for the years 1953-61 should continue at Kew under the same arrangements as at present. It is assumed that the F.A.G.S. contributions will be continued on at least the present scale ; it is hoped that some additional funds may be forthcoming from other sources.

II. That not later than 1961 a small committee, appointed by I.A.S.P.E.I. but with power to co-opt additional members, should endeavour to arrange for the future collation and reduction of seismological data. If suitable plans can be drawn up, the committee should be empowered to implement them without waiting for the Assembly of 1963.

In conclusion, I wish to thank the Officers of F.A.G.S. for their sympathetic help, and to set on record my deep appreciation of the devoted labours of Mr Hughes and the Staff of the I.S.S.

APPENDICES TO THE REPORT BY THE HON. DIRECTOR OF THE I.S.S.

I. — *REPORT OF THE HON. DIRECTOR OF THE I.S.S. FOR THE YEAR 1957 NOVEMBER 1 TO 1958 OCTOBER 31*

Staff. In addition to the Assistant Director, Mr J. S. Hughes, M. A., the Staff consists of three full-time members, one of whom, Mr H. J. Gulley, was engaged this year in order to deal with the increasing volume of data received and to catch up with the arrears of publication. In addition, there are two part-time members. My special thanks must be accorded to Mr Hughes and his Staff for the devotion with which their work has been carried through.

Preparation and Publication of the I.S.S. The first three quarterly numbers of the I.S.S. for 1950 have been published during the present year. Unfortunately, the issue for 1950 October—December is not quite ready ; this is a disappointment, and is due largely to the exceptional size of the July—September number, which occupies 372 pages, as against the average of 200 pages per number for 1949 and 180 for 1948. In fact, the first three quarters of 1950 occupy the same number of pages as the whole of 1949.

This poses a serious problem, at which I hinted in my Address at Brussels in 1951. Apart from considerable fluctuations from quarter to quarter in the number of earthquakes recorded, the increase in the number of stations since the war, and presumably the general improvement in the sensitivity of the instruments, have resulted in a much greater volume of data, and this recent rise has considerably slowed up the rate of production of the I.S.S. Moreover, the work involved is found to increase more rapidly than the number of observations received. Careful consideration has been given to the possibility of abbreviating the I.S.S., e.g. by omitting small earthquakes, by cutting down the number of station readings used in determining an epicentre or by omitting the « Additional Readings ». None of these suggestions receives support from seismologists ; for instance, some of the small shocks are particularly interesting, and valuable information has been derived from « Additional Readings ». From a geological point of view, the completeness of the I.S.S. is essential to systematic studies of seismicity ; a set of observations once discarded is, for practical purposes, irretrievable. These difficulties, which will increase as the years pass, and will be embarrassing when the data from new I.G.Y. stations (many of which are expected to operate permanently) are being worked on, are being borne continually in mind.

The stock of Jeffreys-Bullen Seismological Tables, for which there is a steady demand, was nearly exhausted, and a new supply has been printed by litho-offset from the original hand-set tables. In view of the increased cost of production the sale price has been raised to £1 per copy.

Finance. It is pleasant to report that the outlook for the immediate future is much more cheerful than in my last Report. The International Council of Scientific Unions has just made an allocation of 6,000 dollars for 1959, and in addition has made a special allocation of 3,000 dollars for 1959, to be renewed in 1960 and 1961 — the latter provision being conditional on the I.S.S. being brought up-to-date in three years. In addition, the Government of Canada has made a grant of 1,000 dollars per annum for three years, of which the first instalment was received during the present year. The International Association of Seismology and the Physics of the Earth's Interior has promised a subvention of £400 per annum for the three years 1958 - 1959 - 1960 ; the 1958 contribution will be accounted for in the next financial year of the I.S.S. On behalf of the Committee for the I.S.S. I wish to record my sincere thanks to those bodies which contributed to the funds of the I.S.S. during the past year and to those who have promised support in 1959.

Accomodation. The project is still housed at Kew, and my special thanks are accorded to the Director of the Meteorological Office and the Director of Kew Observatory for continuing to provide accomodation for the I.S.S. and for administrative help in connexion with Staff salaries.

Financial Statement for the year ended 31st October, 1958

(expressed in £ s. d.)

1956/57	*Receipts*		
	Grants :		
2,000 — —	H. M. Treasury (per Royal Society)	2,000 — —	
	International Council of Scientific Unions	1,571 8 5	
1,071 8 7	United Nations Educational, Scientific and Cultural Organisation		
1,200 0 0	International Association for Seismology and the Physics of the Earth's Interior		
	Government of Canada	374 13 8	3,946 2 1
129 3 1	Sales of Literature		88 15 5
52 15 1	Deposit Account Interest		52 11 8
4,453 6 9	Total Ordinary Receipts		4,087 9 2
1,369 18 4	Cash at Bankers and in Hand 31st October 1957		1,924 15 8
£5,823 5 1			£6,012 4 10

1956/57	*Payments*		
1,890 10 —	Salaries and Allowances (less Staff Superannuation Contributions)	2,486 19 4	
237 6 —	Superannuation Contributions	254 18 6	
114 1 8	National Insurance	103 7 —	2,845 4 10
1,553 3 6	Printing		1,572 12 11
69 7 —	Stationery and Postage (including typing)		60 — 2
1 — —	Cheque Books		1 — —
17 8 —	Maintenance of Calculating Machines		18 14 —
6 6 —	Accountancy Charges		4 4 —
9 7 3	Miscellaneous and Travelling Expenses		13 9 6
3,898 9 5	Total Payments		4,515 5 5

	Cash at Bankers 31st October 1958 :		
1,597 11 8	Deposit Account	250 3 4	
324 3 6	Current Account	1,244 14 10	
		1,494 18 2	
	Petty Cash in Hand 31st October 1958 :		
3 — 6	London	18 5	
Nil	Cambridge	1 2 10	1,496 19 5
£5,823 5 1			£6,012 4 10

Auditors' Certificate

We have prepared the foregoing Financial Statement from the books and vouchers, and certify the same to be correct in accordance therewith.

Norwich Union Buildings
Downing Street, Cambridge
8th January 1959.

Peters, Elworthy & Moore
Chartered Accountants.

II. — *REPORT OF THE HON. DIRECTOR OF THE I.S.S. FOR THE YEAR 1958 NOVEMBER 1 TO 1959 OCTOBER 31*

Staff. The staff of the I.S.S. has been enlarged during the past year by the engagement of Mr Muir, and now consists of :

J. S. Hughes, M. A. (Assistant Director), Mrs I. E. Sanders, J. H. Wavish, B. Sc., H. J. Gulley, G.A.C. Muir, B. Sc., and some regular part-time workers. The project is still carried on in accomodation kindly provided by the Director of Kew Observatory, who continues to allow much of the financial administration to be carried out by a member of the Observatory staff. I wish to express my gratitude to Mr Hughes and the staff of the I.S.S. for their loyal co-operation in maintaining the high quality of this publication.

Publications. Including the October—November number in process of distribution the four quarterly parts for 1951 have been printed during the past year. This represents about 1,000 pages, and is the equivalent of seven quarterly numbers of the size of those published about five years ago. As mentioned last year, the continued increase in size of the I.S.S. indicates that a much greater volume of station readings is now being received, and despite an increase in the actual work of preparation, this has largely negatived the strenuous attempt to overtake arrears. An added delay was occasioned, as with most British publications, by the strike in the printing trade.

In the hope of accelerating publication it has been reluctantly decided to omit both the "Additional Readings" and the lists of readings for which no epicentre is definitely indicated. The former will be much regretted by seismologists, for the Additional Readings have in the past yielded valuable information about phases not systematically listed in the I.S.S.; but with the present growth of seismological studies these lists are becoming unmanageably large, and future progress in studying, for instance, waves through the central core is likely to come most profitably from the comparative study of the actual seismograms of a shock. The omission of the other lists of readings is, I think, no great loss; apart from some general indications of seismicity they are contributing little to our knowledge of the Earth's constitution. These omissions, it is estimated, will amount to one-quarter or one-third of the total number of pages at present issued.

Finance. During the past year expenditure has exceeded income by £ 557 : this reflects the efforts made to overtake arrears of computation and publication. The clerical work of extracting information from station bulletins and collating it for determinations of epicentres involves personal judgment and consumes much time ; this accounts for quite a considerable part of the cost of production. The bank balance is now so perilously low that it has been necessary to hold up payment of the last bill for printing until further funds have been received.

The project comes officially under the authority of the International Association of Seismology and the Physics of the Earth's Interior, and this Association is at present furnishing an annual subvention of £ 400. The British Treasury is continuing to pay £ 2,000 annually (on the understanding that every effort is being made to overtake arrears of production), and the Government of Canada has given 1,000 Canadian dollars in the current year. During the year 4,500 U.S. dollars have been received from F.A.G.S., who promised a further 3,000 in 1959 conditional on the production of seven quarterly numbers during 1959. Unfortunately the above-mentioned great increase in the volume of data now being received has made it impossible to claim these 3,000 dollars ; I wish to set on record my gratitude to the Officers of F.A.G.S. for their sympathetic and helpful attitude in this time of financial stringency.

The idea that the free issue of the I.S.S. should be suspended, and a fair price charged for it, is not one that has been met with any enthusiasm by seismologists with whom I have discussed it. But unless ample additional revenue is forthcoming from other sources I see no other way of financing the project. A small charge would scarcely repay the cost of collecting it; the price would have to be an economic one; and the decision must be taken in the near future.

The Future of the I.S.S. Seismologists appear to be unanimous that as an instrument of record and research the I.S.S. should be continued substantially in its present form. However, the number of stations, and their instrumental equipment, continue to increase, and the stimulus of the I.G.Y. will accentuate this development. The need is now generally felt that there should be more stations in undeveloped regions, particularly in the Polar Regions, and we are in sight of the installation of seismographs on the floor of the oceans where at present there is a great gap in our world network. This poses a difficult problem of organisation. Since the accuracy obtainable from a limited number of high-grade stations far outweighs what is got from a large number of stations of low reliability, it may be possible for national committees to help by designating what stations should be used in epicentral determinations : such a discrimination by the I.S.S. staff would, of course, be difficult and invidious. It might be helpful if countries in seismic regions would accept responsibility for working-up the data for local shocks, while still maintaining their publication in the I.S.S. A memorandum on these lines was submitted to the European Seismological Commission at Alicante in October 1959, and I hope the matter can be fully discussed at the U.G.G.I. meeting at Helsinki in 1960.

Acknowledgements. My thanks are due for the continued cooperation of all the stations that have supplied material for the I.S.S. It is hoped that all stations will send in their data *as early as practicable* and *direct* to the I.S.S. I am grateful to all the organisations mentioned above who have given subventions for this work, and once again I record my thanks to the Director of the Meteorological Office and the Director of Kew Observatory for continuing to house the project and grant administrative help free of cost ; without this aid the present budget would be totally inadequate.

Financial Statement for the year ended 31st October, 1959
(expressed in £ s. d.)

1957/58			*Receipts*						
			Grants :						
2,000	—	—	H. M. Treasury (per Royal Society)	2,000	—	—			
1,571	8	5	International Council of Scientific Unions	1,607	2	10			
			International Association of Seismology and Physics of the Earth's Interior	800	—	—			
374	13	8	Government of Canada	367	19	7	4,775	2	5
88	15	5	Sales of Literature				210	19	2
52	11	8	Deposit Account Interest				7	6	9
4,087	9	2	Total ordinary receipts				4,993	8	4
1,924	15	8	Cash at Bankers and in Hand 31st October 1958				1,496	19	5
£ 6,012	4	10					£ 6,490	7	9

1957/58			*Payments*						
486	19	4	Salaries and Allowances (less Staff Superannuation Contributions)	3,539	3	5			
254	18	6	Superannuation Contributions	225	6	—			
103	7	—	National Insurance	133	3	8	3,897	13	1
1,572	12	11	Printing				1,567	18	11
60	—	2	Stationery and Postage (including typing)				79	19	7
1	—	—	Cheque books				1	—	—
18	14	—	Calculating machines				88	7	6
4	4	—	Accountancy Charges				—	—	—
13	9	6	Miscellaneous and Travelling Expenses				15	15	6
4,515	5	5	Total Payments				5,650	14	7
			Cash at Bankers 31st October 1959						
250	3	4	Deposit Account	1,004	4	—			
1,244	14	10	Current Account	135	13	6			
				1,139	17	6			
			less outstanding cheques	301	4	—			
				838	13	6			
			Petty Cash in Hand 31st October 1959						
	18	5	Kew		16	5			
1	2	10	Cambridge		3	3	839	13	2
£ 6,012	4	10					£ 6,490	7	9

Auditors' Certificate

We have prepared the foregoing Financial Statement from the books and vouchers, and certify the same to be correct in accordance therewith.

Norwich Union Buildings,
Downing Street, Cambridge. January 1960

Peters, Elworthy & Moore
Chartered Accountants.

6. — Discussion on I.S.S.

Sir Harold Jeffreys refers to the difficulties of the ISS and expresses the thanks of the Association to Dr. Stoneley and Mr. Hughes for their work.

Prof. Byerly suggests making an alternative budget with vastly large-enabling mechanization of epicenter locations rapidly. Then see if funds will not come. I think they will. Do not delay.

Dr. Stoneley : Sir Harold Jeffreys will, I feel sure, corroborate my recollection that the system of using punched cards was looked into some years back and found hardly worth while.

Sir Harold Jeffreys : At the time when I ceased to be the Director of the ISS we were required to produce 7 numbers per year, and it looked as if we should be able to continue this. But these hopes have been dashed by the increase in the amount of material. — A Royal Society committee had considered the problem of using automatic calculators, but made no definite recommendation. Actual calculation does not actually take the largest part of the time. The greatest part is the copying of the information in station bulletins on to standard cards, and there is no apparent way of reducing it.

Dr. Hodgson : I should like to support the suggestion of Dr. Stoneley that a committee be set up to consider the handling of seismic data, but I hope we may consider the problem in its broadest sense and not just as concerning the ISS. The BCIS is also in difficulty, the USCGS is spending a great effort and a large number of stations are involved in preparing their own bulletins and filing the bulletins of others. This is incompatible with a world of modern communication and modern computation methods. We must aim at a central agency to serve the complete needs of seismology. — Bulletins seem to us to be inconsistent in this modern world. We in Canada are expanding our network to about 30 stations. The records from all these stations, with magnification curves, are being placed on microfilm ; copies of these records can be sent airmail anywhere in the world, allowing one month for processing the records. This service makes bulletins obsolete.

Prof. Wadati : I should like to express our sincere thanks to Prof. Jeffreys, Prof. Stoneley, Mr. Hughes and other members of the staff, who have carried out this important and valuable but very laborious ISS work. I support the proposal of Prof. Stoneley to set up a small committee, to arrange for the future collection and reduction of seismological data. It is my personal desire, that this committee treats not only ISS but also publications of world-wide seismological data in general, both preliminary and complete, if possible.

Mr. Murphy : In substantiating Prof. Stoneley's comments about the increase of seismogram readings becoming available in future years, I have the following statistics to offer. — At the present time the estimated annual readings from each station is 73'000 ; during the IGY period an estimate is 140'000—175'000 per year, and after the proposed station improvement program of 1960 and 1961 is implemented it is anticipated the total number of readings will be 900'000. These data are staggering and present a serious publication problem for processing and publishing the results. — Very shortly it is planned at the U.S. Coast and Geodetic Survey to determine all epicenters with an IBM 650 computer. Initially the volume of epicenters determined will be about the same as the present rate (1'400 per year) but within a few months the volume will be increased a number of times, contingent more on the availability of accurate data rather than the number of earthquakes. — I heartily agree with Prof. Stoneley that the problem of the ISS publication be immediately investigated and that a committee be established and be empowered to carry out the recommendations, with necessary IUGG approval, before the next triennial.

Dr. Willmore : It is clear that the situation is already out of hand, and that only a large computing centre can provide the necessary facilities for handling the flow of data. It also seems clear, that the concept of the station bulletin is out of date — for a glance at the programmes of our meetings will show that only a small fraction of modern work is being based on the sort of data which individual station operators can put into their bulletins. The essential requirements are that the focal data of all earthquakes should be available promptly — perhaps fault-plane solutions too, although that might be a later development. We also need figures for the distance of each epicentre from each station. If we had that, coupled with a rapid availability of copies of records as suggested by Dr. Hodgson, future research would be immensely facilitated.

Prof. Richter : 1) On Dr. Willmore's remarks : We have not yet heard the papers on seismic geography. Research in this field necessarily works with reported data. 2) Could not the ISS be financed in part by sale outside the organization ? There might be even sale for offset copies of past issues.

Prof. Bullen : My experience is that it is most desirable to publish the readings of individual phases, in addition to epicentres, origin times, etc. Even if the computation of epicentres is programmed, the results can be regarded only as first approximations by research workers who seek to use the data to a fine degree. Other readings than P can, for example, influence judgments on epicentres. When statistical methods are applied to large quantities of data, it is, moreover, often not practicable to read in person a sufficiently large number of seismograms. Hence I feel that it would be a major loss if any of the detail now appearing in the ISS were to be eliminated. At the same time, I recognise that we are faced with something like a crisis, in which strong steps may have to be taken.

Gen. Sec. Laclavère emphasizes the need of definite plans for the ISS in order to get more funds.

Dr. Stoneley promises more definite proposals later and suggests Prof. Wadati and Dr. Willmore to join the ISS Committee.

This is adopted by the Association.

7. — Constitution of a Nomination Committee.

The following persons are elected members of the Nomination Committee. Past and present Presidents of the Association : *Dr. Stoneley* (chairman), *Prof. Bullen, Sir Harold Jeffreys* ; Members of the Executive Committee : *Miss Lehmann, Prof. Pekeris, Dr. Rit-*

sema, Dr. Vesanen ; Appointed by the National Committee of the U.S.S.R. : *Mrs. Dr. Kondorskaya* ; Appointed by the National Committee of the U.S.A. : *Mr. Murphy.*

8. — Project of investigation of the upper mantle.

Prof. Beloussov presents the project to the Association :

My feeling is that we are in the situation when it becomes very important to precise the scientific purposes of the work of the Union. It is quite obvious, that our Assemblies are very useful as forums of geophysics and they contribute very much to the development of the geophysical sciences.

Nevertheless the science is growing very rapidly, the quantity of scientific problems is increasing from month to month and the interests of researchers diverge more and more. As the result of that our Assemblies are overloaded by an enormous quantity of communications very loosely bound together.

We need more precise programme of our activity from another point of view, from the point of view of our future existence. If we cannot elaborate some more precise programme, the main activity will pass to the Special Committees and other specialized bodies. I am not against the Special Committees, but it is quite right that they are *Special* and each of them covers only some comparatively narrow field. Only the Union gives the possibility to carry out more and more deep researches on the basis of the cooperation of different branches of geophysics. This happy opportunity we must not loose, on the contrary we must permanently strengthen the Union.

My idea is that the Union should undertake two or three main problems and try to concentrate upon them as its main activity and its resources.

The choice of such problems is very difficult. The problems must be sufficiently well defined and at the same time they must be sufficiently broad in order to give place for the joint application of the different geophysical disciplines.

May I propose one problem as an example : *The Upper Mantle and its influence on the development of the Earth Crust.*

This problem is very interesting purely scientifically, but it is also very interesting from a practical point of view since in the upper mantle are hidden the deep origins of all tectonic and magmatic phenomena. The applied geology is moving at present deeper and deeper and one can foresee that in the nearest future the problem of the upper mantle as the source of the mineral and energetic resources will become quite practical, but let us take the scientific aspect. Personally, as a specialist in tectonics, I know very well that I cannot understand anything in the tectonic development of the crust without having sufficient information about the upper mantle.

This problem may gather Associations of Seismology, Geodesy, Volcanology, Oceanography and may be Geomagnetism.

The following questions may be included in the programme of the problem :

1. Chemical and mineralogical constitution of the upper mantle.
   a) Seismic research,
   b) Gravimetrical research,
   c) Volcanological research,
   d) Study of the properties of rocks under high pressures,
   e) Theoretical studies,
   f) Deep drilling.

2. The thermal regime of the upper mantle.

3. The processes in the upper mantle and their manifestation in the tectonic and magmatic phenomena :
   a) differentiation and selective smelting in the upper mantle,
   b) the volcanic foci and their evolution,
   c) the development of magmatic processes,
   d) metamorphism as a factor of deep tectonics,
   e) the constitution of the upper mantle in the different tectonic zones of the continents and oceans,
   f) the tectonic development of the crust and its relation to the deep processes,
   g) recent movements of the crust and the alteration of the different geophysical fields in time, and so on.

That is only a preliminary sketch of this programme. If the idea is adopted in principle, we may appoint some small committee to propose a draft programme during this Assembly and suggest the organisational scheme. We may discuss and adopt the programme and constitute some body for the coordination of work.

Then we may distribute this draft programme among the National Committees inviting them to study the question and to precise their possible participation.

During the IGY we were looking mostly upwards — to the upper atmosphere, to the space and the solar activity, but under our feet after some kilometers only begins the area which is quite unknown. We begin now to prepare ourselves for the space travels. But let me say, that after each space travel we shall have to return to our old Earth which is and will remain our home and that home we do not know completely. I think that our duty is to begin an internationally organized campaign for the scientific conquest of the depths of the Earth.

I am sure that in many countries we may find people who will be enthusiasmed with this kind of scientific cooperative enterprise.

Prof. Bullen : I have much sympathy with Prof. Beloussov's desire to make discussions at the Association's meetings. Sometimes we suffer from great diffuseness. But there is the dilemma that if the projects such as Prof. Beloussov suggests are wide, we shall be no better off than we were before. If they are narrow, then there is a risk of excluding important work outside the scope of the selected projects. The idea of symposia on the more important topics, which has worked at some previous meetings, but with the inclusion of sessions covering other work, seems the most satisfactory way. A further point is the question of finance. If the proposal entails a subvention from the Union, then since there is an upper bound to the total Union funds, there is a risk of financial difficulty in other directions. This aspect should be closely watched.

Prof. Press : If it is the purpose of Prof. Beloussov's suggestion to focus our attention on important problems for special research and symposia, then it is a good one. However, our Association's first purpose should be always to provide a vehicle for presentation and publication of research results of investigators working in fields which they themselves have chosen.

Prof. Grenet : Je pense que les relations magnéto-telluriques doivent fournir des renseignements importants sur le manteau et sur sa partie supérieure. Les pulsations de 6 à 60 sec enregistrées à Tamanrasset prouvent l'existence d'une couche très conductrice correspondant peut-être à la partie supérieure du manteau. Les travaux de M. Rougerie (de Paris) semblent fournir des renseignements sur la conductibilité électrique du manteau.

Prof. Rothé : Une commission pour l'étude de ce projet est une bonne chose. Je rappelle que la commission des explosions alpines a fait un travail expérimental de collaboration internationale et c'est là un exemple à suivre.

Prof. Beloussov proposes a committee from several associations for the organization of this research.

Prof. Ewing, Prof. Magnitsky, and *Prof. Press* are elected as members of this committee.

9. — The problem of publications.

Prof. Beloussov presents the Russian suggestions for re-organization of the publications of the Association.

As these suggestions have been put forward already on an earlier occasion, the Assoc. Sec. Gen., *Dr. M. Båth,* sent a circular letter, dated Feb. 1, 1960, to present and past presidents and to members of the Executive Committee, in order to prepare a discussion at the Helsinki Assembly. The circular letter had the following wording :

The following proposals have been made by our Russian colleagues through one of our Vice Presidents, Prof. Y. V. Riznichenko :

1) It is not normal to publish as a rule the reports made at assemblies of associations in other journals. It would be better to publish them in *one* issue.

2) The size of chronicle-material (minutes of meetings, organization questions, etc.), which has no first rate importance, may be diminished. On the other hand, the publications of scientific reports, communications made at assemblies of associations and at the general assembly may have a bigger size.

Point 2) above concerns also the Comptes Rendus of our association. According to Prof. Beloussov, who has personally expressed his opinions to me, this publication should be changed as follows : summaries of papers should be excluded and only a reference be given to the complete publication ; furthermore, the discussions should not be given as complete as now but only the results ; on the other hand, resolutions, list of addresses, and national reports should be given as hitherto. The size of the Comptes Rendus could thus be diminished, and the money thus saved could instead be used for publication of the papers presented at the assemblies.

Even if this proposal may seem to be desirable, there are a number of difficulties. The money thus saved will not be sufficient for publication in full of all papers presented. Prof. Rothé reports that for instance Fasc. 20 of the Publ. Bur. Centr. Séism., which has just appeared and which contains only a fraction of the papers presented at Toronto, amounted to a cost of 1.900.000 French Francs (19.000 New French Francs), even if the most favourable printing conditions were utilized. Moreover, the suggestion to publish all papers in full is against the recommendations of the financial committee of the Union.

As there may be different opinions on the two proposals mentioned, the matter will be discussed in the forthcoming Helsinki Assembly. In order to prepare this discussion we would appreciate very much to hear your opinion at your earliest convenience.

The letters obtained in reply are here given in summary form.

Dr. Stoneley : I am very glad that this subject has been raised, although I do not entirely agree with the suggestions made. Firstly, I am completely against the publication *in full* of papers presented at our meetings. These should, I consider, be published in reputable journals particularly in view of the need of careful refereeing (which is somewhat invidious in an international publication). Secondly, I would like short summaries of papers to be published in our Proceedings, because it is not always easy to look up the journal in which a paper is published. Thirdly, I would agree that Minutes of meetings, questions of organisation etc., should be kept down to a minimum. The publication of scientific reports is justifiable, and I would give priority to matters of general or world-wide scientific interest as against specialised and local questions.

Prof. Bullen : My immediate reaction is that we need to be cautious in any changes that may be made in the character of the Association's publications. With the finance available, I cannot see that it is possible to publish anything like all the papers presented at a meeting. Hence some compromise is inevitable. So far as I am aware, the present publication arrangements are meeting requirements as well as can be in all the circumstances. While I am not necessarily opposed to any change, I think that we should be at the greatest pains to see that we do not spoil a system which, so far as I can judge, is giving fairly general satisfaction.

Miss Lehmann : I do not see any advantage of having all the papers presented at the meetings of the Association published in one volume. First, there is the cost to consider. It will probably be prohibitive. Secondly, it will obviously take a very long time to have all the papers collected and published. The publication of papers that are ready for print when they are presented, will be greatly delayed. Thirdly, a volume issued by the Association will not obtain so wide a distribution as the scientific journals and to many scientists it will not be easily accessible.

Dr. Ritsema : I fully agree with point one in your letter. Being able, however, to guess the costs for such a complete and detailed publication, and also the limited means of the Association, it seems to me a hopeless task to make an improvement in this sense, not to mention a radical solution of the problem.

Moreover, the enormous increase of papers to be published will result in a proportional postponement of the day of issue. Also there will always be a part of the reports that is already, or that is going to be published in some institutional series. So a complete synopsis of the sessions will never be reached, also if the means are there.

In view of the demands, the gain in excluding summaries of papers from the Comptes Rendus of the Association seems negligible. I personally should very much regret the rejection of the summaries. The situation we are confronted with is such that just these summaries give the gist of what has been discussed at the assembly, and not the few papers published in full in the Travaux Scientifiques. Eventually, the discussions could be compressed or neglected. With each summary a reference should be made where the full paper will be published.

Dr. Vesanen : I have no negative comments. The proposals are very good and we all know that there is much to do in that respect. My opinion is that the matter belongs to the normal developing process.

A brief discussion takes place during the session.

Dr. Stoneley expresses the views, which have already been given above.

Prof. Richter : The Proceedings of the assemblies are of particular value to those who were unable to attend. Greater care, if possible, should be applied to avoid the wasteful duplication in the Transactions of papers, which have in the meantime appeared elsewhere. Valuable contributions, not otherwise duplicated, have appeared in the Transactions; some of these were not presented in full at the assembly itself.

Mr. Eiby : Seismologists in distant countries like New Zealand who can only attend meetings at very infrequent intervals, find full reports of the proceedings of great interest. They help to convey the feeling of the meeting, and are carefully read.

A Publication Committee, consisting of *Dr. Båth, Prof. Karus, Prof. Rothé,* and *Dr. Stoneley,* is elected to discuss the publication proposal.

10. — Seismological dictionary.

Prof. Guyot, Chairman in the Committee for the Seismological Dictionary, gives the following report :

Depuis le congrès de Toronto, la rédaction du dictionnaire séismologique a fait quelques progrès. Ne disposant pas d'une bibliothèque séismologique importante, le président a fait, à la fin de septembre 1959, un séjour de deux semaines au Service Séismologique des Pays de Bade et Württemberg à Stuttgart, où le Professeur Hiller l'a accueilli très aimablement et a mis à sa disposition les publications de son institut. Après ce stage, les définitions de tous les termes concernant la théorie de l'élasticité et son application à la séismologie, la théorie des ondes séismiques, la structure interne de la terre ont été rédigées et envoyées à Madame Labrouste pour qu'elle les transmette aux séismologues chargés de les contrôler. Un fichier a été constitué qui permettra de classer par ordre alphabétique tous les termes définis.

Le Prof. *Guyot* tient encore à faire remarquer combien la tâche confiée à la commission est lourde puisqu'en fait tout le travail est réparti entre deux personnes : Madame Labrouste et le président. D'autre part, ce dernier ne dispose d'aucun subside et c'est à ses propres frais qu'il s'est rendu plusieurs fois à Paris pour voir Madame Labrouste et à Stuttgart. Il est regrettable que le travail n'ait pas pu être partagé entre plusieurs séismologues spécialistes qui auraient chacun traité une partie, le président se chargeant de coordonner toutes les définitions.

Dr. Hodgson reads the report in translation into English.

Mme Labrouste reminds the Association of the committee which was elected at the Toronto Assembly in 1957 for the work on the seismological dictionary (see C.R. N° 12, p. 204).

The session is closed at 17.25.

8th SESSION

THURSDAY, JULY 28 (morning)

Program

11. — Publication of the IGY results.

1. — *V. V. Beloussov :* Introduction.
2. — *J. P. Rothé :* Report on the Seismicity of the Antarctica.
3. — *J. H. Hodgson :* Report on the Seismicity of the Arctic.
4. — *K. Wadati :* Report on Microseisms in the Pacific.
5. — *R. Stoneley :* Report on Microseisms in Eastern and Western Atlantic.
6. — *K. E. Bullen :* Report on Ice-Thicknesses in the Antarctica.
7. — *J. P. Rothé :* Report on Bibliography.

The session is opened at 9.15 with *Prof. Beloussov,* President of the Commission for IGY, Seismological works, as chairman.

11. — Publication of the IGY results.

1. — *Prof. Beloussov* gives an Introduction to this session, devoted to the preparation of the volume on seismology of the Annals of the IGY.

Prof. Beloussov suggests that the introductory chapter should contain national reports on seismological works during the IGY, also suggestions for improvements etc. The development of the works should be described.

These recommendations are approved by the Association.

2. — Seismicity of the Antarctica.

Le Professeur *Rothé,* chargé d'établir le chapitre concernant la séismicité de l'Antarctique, présente son rapport.

Une liste de 88 épicentres antarctiques et subantarctiques a été préparée principalement d'après les données publiées dans le Bulletin mensuel du Bureau central, D'après cette liste, une carte d'épicentres a été dessinée. Le Professeur Rothé commente cette carte en en soulignant les traits principaux. Les observations faites pendant l'A.G.I. ont permis de préciser la trace d'une zone à peu près continue d'épicentres s'étendant depuis le sud de l'Océan Indien jusqu'à l'île Macquarie et se poursuivant dans le sud de l'Océan Pacifique jusqu'à l'île de Pâques.

La séismicité du continent antarctique proprement dit est très faible ; des séismes locaux d'origine volcanique ont été signalés à proximité de Scott Base et de l'île Decepcion. Des reproductions de séismogrammes sont présentées.

Il faut signaler qu'en dehors des séismes dont les épicentres sont bien déterminés de très nombreuses inscriptions isolées ont été recueillies dans les stations antarctiques, 100 à 150 chaque mois pour l'ensemble des stations. La trop faible densité des stations antarctiques ne permet encore qu'une étude incomplète de la séismicité.

Plusieurs problèmes de géographie séismologique restent posés : jonction de la zone séismique des Antilles du Sud avec la zone séismique médiane indo-atlantique, diminution rapide de la séismicité dans la péninsule antarctique.

En terminant, le Professeur Rothé mentionne certains travaux séismologiques concernant la structure de l'Antarctique : la partie orientale du continent antarctique est à structure continentale avec une épaisseur crustale d'environ 35 km ; au contraire, au delà de la ligne joignant la mer de Ross à la mer de Bellingshausen, on est probablement en présence d'un groupe d'îles qui viennent se raccorder à la « péninsule antarctique » et à l'Arc des Antilles du Sud. Le véritable continent antarctique est sans doute moins étendu qu'on ne pourrait le penser au premier examen de la carte géographique.

Prof. Rothé promises a definite manuscript towards the end of 1960 for the IGY proper, i. e. July, 1957 - December, 1958. This is accepted by the Association.

Dr. Hodgson : The problem of dealing with small earthquakes recorded at one or two stations concerns also other regions, e. g. the Arctic.

Dr. Soloviev : 1) Quel est le nombre des séismes isolés (sans épicentres connus ? 2) Quel est l'accord parmi les données différentes (BCIS, USSR, USCGS) sur les épicentres des séismes importants ?

Prof. Rothé, in reply : 1) 88 épicentres pour l'ensemble de l'année géophysique ; environ 100 séismes isolés par mois, soit environ

1800 séismes. 2) En général, bon accord à ½ degré près pour les séismes importants ; la précision est seulement de quelques degrés pour les séismes inscrits dans quelques stations seulement.

Dr. Sponheuer : Les magnitudes sont elles déjà déterminées ?

Prof. Rothé : Dans le catalogue les magnitudes sont indiquées ou à défaut le nombre de stations ayant enregistré chaque séisme.

3. — *Dr. Hodgson* reads his Report on the Seismicity of the Arctic.

A committee consisting of the following : *J. H. Hodgson,* Canada (Chairman), *M. Båth,* Sweden, *H. Jensen,* Denmark, *A. Kvale,* Norway, *Mrs. N. A. Linden,* U.S.S.R., *L. M. Murphy,* U.S.A., *E. Tryggvason,* Iceland, *E. Vesanen,* Finland, was appointed in May, 1959, to prepare a Chapter on Arctic Seismicity for the Annals of the IGY. A preliminary draft of this Chapter has been prepared through correspondence. Epicentres have been determined for a large number of earthquakes. These will be listed in the published Chapter. It appears that, in addition, each Arctic station records numerous small earthquakes, which are not recorded at other stations. It has been agreed that these earthquakes will be described in general, but will not be specifically listed in the Chapter. Data on them will be filed with the World Data Centres.

Dr. Stoneley : I fully sympathize with Dr. Hodgson in his difficulty of deciding to what cause one should attribute the many small shocks recorded at one station only. A similar situation has arisen in connection with the records from Halley Bay in Antarctica. These records have all been re-read during 1960 and all the observed shocks will be published in the U.K. report on the Halley Bay Station. However, it is not clear how far these observations refer to a true seismicity of the Antarctic fringe, or how far they are attributable to cracking of ice — especially as Halley Bay Station is on an ice-shelf.

Dr. Willmore : Would it be possible to estimate the distance of the epicentre of each small earthquake from the station which recorded it, and also the magnitude of the earthquake ? In this way, it might be possible to estimate the density of epicentres in the area, even if the individual positions could not be established.

Dr. Hodgson : In the case of well-calibrated stations, such as Resolute, it should be possible to make rough estimates of this type, even though we do not have travel-time curves which refer specifically to the area.

Dr. Soloviev : I propose to have all the data about small undetermined earthquakes at the World Data Centers. It is sufficient to have in the book only a general description of these shocks for each station (with examples of records etc.).

Dr. Hodgson : This suggestion is very satisfactory.

Prof. Richter : In summarizing data on minor shocks in the Antarctic, special attention should be given to those probably originating on the Antarctic continent. Data for such shocks should be presented, if not in full, at least in sufficient detail, and with sufficiently representative illustration, to facilitate thorough investigation.

Prof. Bullen : The question of epicentres in Antarctica interests me especially, because of my association with the Special Committee for Antarctic Research. It has become evident that the Antarctic mainland has extremely few earthquakes. It would therefore be of value to have all data on local earthquakes during the IGY period published, with so much precision as possible.

Prof. Vening Meinesz suggests publishing the seismic and gravimetric results for the Antarctic together in order to arrive at a better interpretation.

Prof. Beloussov says that the gravimetric results do not belong to the volume on seismology.

Dr. Hodgson suggests the use of the same projection for *all* maps, which are used in the study of the IGY results. He further says that the manuscript of the chapter on Seismicity of the Arctic will be ready towards the end of 1960.

A committee, consisting of *Dr. Hodgson, Prof. Richter,* and *Dr. Soloviev,* is elected in order to investigate the problem of how to deal with the small shocks.

4. — Prof. Wadati presents his Report on Microseisms in the Pacific.

For the study of microseisms in the West Pacific area, the standard microseismic, tripartite microseismic, and supplementary microseismic observations were conducted at 17 stations in Japan during the IGY.

The standard microseismic observations were made 4 times daily (0, 6, 12, 18 GMT) at 7 stations and 4 additional observations (3, 9, 15, 21 GMT) were made when a microseismic storm occurred. During the International Days and International Periods, hourly observations were performed.

The tripartite microseismic observations were made at 3 stations during the special period (only when a typhoon was passing through the West Pacific area).

Supplementary observations were made 4 times daily (0, 6, 12, 18 GMT) at 8 stations (not registered CSAGI). Moreover, data of wind waves and swells observed at stations along the coast of Japan and nearby islands were collected.

With the establishment of the Regional Center of Microseismic Observations in the West Pacific Area, the Working Group for Investigation of Microseisms was formed in Japan in October 1957, represented by T. Matsuzawa. Research has been made and many papers were published by T. S. Akima, F. Kishinouye, K. Okano and others.

The said group edited the observational data of microseisms in Japan during the IGY and published 2 reports mentioned below.

"Report of Microseismic and Sea Wave Observations in Japan during the International Geophysical Year 1957/8" No. 1 & No. 2.

This report contains the graphs showing the period of microseisms, daily mean values of amplitude of microseisms and daily height of wind waves and swells etc.

"The Data of Microseismic Observations during Microseismic Storms and of Tripartite Microseismic Observations in the Period of the International Geophysical Year 1957-1958".

This report deals with the observed values of 78 major microseismic storms recorded at each station, including some tripartite observations.

As the regional center of microseismic observations in the West Pacific area, we are now collecting and arranging the data of microseisms observed at each station in the area in order to publish them.

Dr. Hodgson suggests uniform presentation of microseisms for all areas investigated.

5. — *Dr. Stoneley* gives his Report on Microseisms in Eastern and Western Atlantic.

The study of microseisms, despite the vast amount of effort expended over many years, is still without a firmly established basis. Evidently more than one mode of generation is involved, and one hope of the IGY investigations is that the differing causes may gradually be sorted out. The importance of the standing-wave theory of Longuet-Higgins is mentioned. But there is good evidence for other ways of generating microseisms. If any one way can be established quantitatively there is hope that the systematic removal of that type of microseism from the observations, by frequency analysis or otherwise, would make it easier to separate out other types.

Reference is made to the microseismic readings made at a large number of stations during the IGY as recommended and which were collected at the three WDC. In addition special investigations were made during the IGY, which will be briefly mentioned here. The report concerns only the North Atlantic region, as no material has been received for the Southern Atlantic.

In Copenhagen H. Jensen developed a method for determination of the direction of approach of microseisms, which could be conveniently used in routine.

Extensive studies were carried out in the USSR, according to a report by N. V. Veshnyakov. Tripartite stations were in operation at Murmansk, Viborg, Barentsburg, and intermittently also at Yalta, Simferopol, and Pulkovo. In addition to period, amplitude, and azimuth, calculations were made of the phase velocity of microseisms. Special instruments were also set up, as e. g. the Gamburtsev-Galperin azimuthal apparatus, a vector apparatus, and Monakhov's set-up for position-phase correlation. The directions determined pointed in most cases to a cold front origin of the microseisms. To determine the conditions of propagation and to elaborate additional methods of locating the sources, special investigations were carried out. These included the study of refraction effects, furthermore correlations between position of cyclones in the Atlantic and the nature of amplitude and period variations at specific seismic stations, and a study of the effectiveness of excitation of microseisms as a function of cyclone position. It was found that swells reflected against the west coast of Scandinavia produced microseisms (Longuet-Higgins' theory), but also that the Scandinavian mountains produced strong attenuation of the waves which crossed them. The role of the mountains was ascertained also by model studies.

In Great Britain the study of microseisms has been concentrated to the National Institute of Oceanography. In addition to the theoretical research many observations have been studied, and a sensitive three-component seismograph installation has been set up specially for the recording of microseisms. The intention is to develop a storm-warning system in areas at present not catered for. Considerable Love-wave motion has been found to be present in addition to the Rayleigh waves, but in spite of this the direction of approach could be estimated and storms successfully tracked.

In Czechoslovakia Prof. A. Zátopek has over a number of years carried out very detailed investigations of the nature and origin of microseisms recorded at more than 15 European stations. He finds a "first order" source of microseisms in the cyclones of the North Atlantic and a "second order" source in coastal effects of different kinds.

Passing now to the Western Atlantic, there is a report only from U.S.A. A twelve years' program of observational work covering the years 1944-1955 was carried out by the U.S. Coast and Geodetic Survey on behalf of the U.S. Navy, and the discussion of the material and the preparation of the report, which was published in April, 1959, represent the main body of microseismic investigations in this region associated with the IGY. It was concluded that hurricanes, typhoons and other storms at sea are responsible for the generation of storm microseisms, and that such microseisms indicate the presence of a disturbance at sea which may be a tropical storm — if in season. However, there is often a lag by as much as 36 hours between the closest passage of the storm and the maximum microseismic amplitudes, which is explained by the time it takes the ocean swell from the cyclone to reach a coast. The tripartite method of tracking storms was not satisfactory and other attempts using relative amplitudes at several stations were made, which proved partially satisfactory. Several special studies have been made, including the discovery of microseisms in the period range 11-22 sec.

Prof. Bullen : In so far as National Committees find it difficult to present salient features of their microseismic results succinctly, Dr. Stoneley has a well-nigh impossible task in trying to reduce the work of 50 nations. It is evident that he is in need of much help.

Dr. Hodgson, in reply to Prof. Bullen : I could scarcely disagree more. All nations were required in the name of international cooperation to provide vast amounts of data in a specified form. We in Canada have provided this although we were not personally interested in the problem and did not think this was the best way to handle it. Under the circumstances I think those people who wanted the data collected should be required to analyse it. It is most unfair to make a country analyse data which it regards as inadequate on a problem in which it is not interested.

Mr. Murphy : In the U.S.A. there has been no attempt to compile microseismic data during the IGY. There is a serious question as to what results may be derived from these data. In 1947 the U.S. Coast and Geodetic Survey undertook a similar program of compiling data from world stations. Although the data were made available to all stations for research not a single one requested the data. My feeling is that something similar will result with the IGY data.

Dr. Stoneley says that his manuscript is planned to be ready at the end of 1960.

A committee, consisting of *Dr. Hodgson, Dr. Stoneley, Prof. Zátopek,* and *Prof. Wadati,* is elected to study the presentation of the microseisms, including microseisms in the Arctic.

The President, *Prof. Beloussov,* asks the chairmen of the subcommittees to contact nations for which data are still missing. Furthermore, reports on the Earth's crust are called for from countries, which have made such work.

6.— Prof. Bullen gives his Report on Ice-Thicknesses in Antarctica.

At the Moscow CSAGI meeting of August 1958, the task was assigned to me of preparing the section on Antarctic ice-thicknesses for the Seismological Volume of the I.G.Y. Annals. I am sharing the task with Mr. M. J. Goodspeed (Australian Bureau of Mineral Resources, 203 Collins Street, Melbourne, Victoria).

The task involves the collation of results forwarded by National Committees of the six nations which have had programmes in this field, namely Australia, France, Japan, United Kingdom, United States, and the U.S.S.R.

We have now received most of the material needed and are proceeding with the work of presenting it suitably. Where possible, we intend to accompany the results of seismic shooting with gravity results.

Some refraction shooting has also yielded *P* wave velocities below the ice. We intend to refer to these also.

We are seeking to have the finished typescript and drawings in the Editor's hands by the end of 1960 (or February 1961 at the latest).

It is recommended that all relevant material should be sent to Prof. Bullen within two months from the meeting.

7.— Prof. Rothé gives his Report on the Bibliography in the volume on Seismology.

References should be given at the end of each chapter, and a general bibliography should appear at the end of the volume. Material for the general bibliography should be sent to Prof. Rothé, Strasbourg, before November 1, 1960.

It is agreed that our Commission for IGY should be preserved until the publication of the seismological results is finished.

A summary of the decisions reached is given in the proceedings of the 24th session below.

The session is closed at 10.55.

9th SESSION

THURSDAY, JULY 28 (afternoon)

Program

1.— Scientific communications : Island Arcs.

13. — *V. V. Beloussov* and *E. M. Roudich :* The position of the island arcs in the development of the Earth's structure.

14. — *J. Ewing, J. Hennion,* and *M. Ewing :* Seismic refraction studies of island arcs and oceanic trenches.

15. — *M. Talwani, J. L. Worzel,* and *M. Ewing :* Gravimetric studies of ocean trenches.

16. — *P. S. Weizman, E. I. Galperin, S. M. Zverev, I. P. Kosminskaya, K. M. Krakshina, G. G. Mikhota,* and *I. V. Tulina :* The structure of the Earth's crust in the region of the Kurile Island Arc.

17. — *S. A. Fedotov, V. N. Averianova, A. M. Bagdasarova,* and *I. P. Kuzin :* Preliminary results of detailed seismic investigation of the southern Kurile Islands.

18. — *R. W. Fairbridge :* The Melanesian Border Plateau, a zone of crustal shearing in the SW Pacific.

19. — *G. S. Gorshkov :* Petrochemistry of volcanic rocks in connection with the formation of island arcs.

20. — *J. P. Rothé :* Séismes volcaniques, projet d'atlas de séismogrammes.

This symposium is held together with IAG and IAV. It is opened at 15.00 with *Prof. Vening Meinesz* as chairman.

1. — Scientific communications : Island Arcs.

13. — *Prof. Beloussov* presents the paper by *V. V. Beloussov* and *E. M. Roudich :* The position of the island arcs in the development of the Earth's structure.

1. The origin and the structure of the island arcs should be considered on the background of the formation and development of the oceanic depressions.

2. Convincing geological data indicate that the oceans are comparatively new phenomena on the Earth's surface. In any case, during the mesozoic and cainozoic eras they have suffered considerable deepening and expanded their area by engulfing the surrounding land (the process of "oceanisation").

3. In view of the aforesaid it could be concluded that the oceanic structure of the Earth's crust is secondary and is formed as the result of destruction and substitution (basification) of the continental crust. This process goes on in the conditions of tension and crevassing of the crust and powerful basalt volcanism.

4. The analysis of the geological structure and the history of the development of the island arcs gives evidence to distinguish two types. The island arcs of the first type represent arching folded ranges, similar to the folded arcs on the mainland. They were formed in the geosynclines, but in the process of basification the back-lying interior massives subsided and the arcs themselves are still preserved in the form of blocks of the continental crust amidst the oceanised areas (Japan, Indonesia, the Antilles Isl.). During the process of the tension of the Earth's crust these weakened geosyncline zones became places of formation of large fractures which provoked the development of intensive volcanism.

The arcs belonging to the second type are connected with the previous geosyncline development. They were formed as the direct result of the Earth's crust tension, in the conditions of which the oceans developed. The tension produced the formation of deep fractures, the arching of which was excited by the curving of the trajectories of the tensional stresses in the process of the fractures extension. The fractures facilitated the differentiation of the material of the mantle and the surfacing of the light material which formed these arcs (the Aleutian, the Kuril, the Marianas-Bonin). Being more young and more "active" the arcs of the second type cross the arcs of the first type.

5. The opening of the deep fractures, connected with the development of the ocean, encouraging the material differentiation of the mantle, in some cases result on the surface in phenomena similar to the geosyncline development. However, the island arcs cannot be identified with the geosynclines.

6. The asymmetry of the Pacific Ocean is characterised by the bordering of the ocean on the East with the Cordillieras and the Andes zone, which is unitary in its development and structure of the crust, while on the Western outskirts of the ocean the crust has a mozaic structure. In this area the processes of basification are selective in character. They first of all overlap the regions, where the formation of the continental crust is completed, and flow around the zones, where the increase of the thickness of the continental crust is still in progress due to the differentiation.

7. The basification of the Earth's crust and the formation of the oceans is the last direction in the development of the Earth determined by the radioactive warming of the Earth's interior and the melting out to the surface of the more deeper material of the mantle.

The paper has been published in Russian in *Sovetskaya geologia,* No. 10, 1960.

Prof. Vening Meinesz : I have heard with great appreciation the paper by Prof. Beloussov, and I want to ask whether his theory can account for two things : 1) The curved shape of the island arcs; 2) The correlation which the spherical harmonic development of the topographic elevations of the solid Earth's surface over the whole Earth shows with the distribution over the Earth's mantle of convection currents, i. e. currents over the whole thickness of the mantle, currents over two layers in which the mantle divides itself, over three layers in which it divides itself, and so on up to seven layers.

Prof Beloussov : 1) The curvature is due to the distortion of the stress trajectories in the crust due to the initial fracture of mantle material. 2) Convection currents are believed to occur in the mantle but are not so much the result of thermal forces as a manifestation of chemical differentiation.

14. — *Dr. Hennion* presents the paper by *J. Ewing, J. Hennion,* and *M. Ewing :* Seismic refraction studies of island arcs and oceanic trenches.

Many seismic refraction measurements have been made in and around the West Indies arc, the Puerto Rico Trench, and the Cayman Trough in the Carribean area, and a few measurements have furnished preliminary results from the South Sandwich Trench and arc. These studies have shown that in the trenches on the outside of the arcs, the high-velocity crust and the mantle are depressed or downfaulted to a depth several kilometers below their normal level in the adjacent ocean basins. The structure under the Cayman Trough, on the other hand, is very similar to that in a typical ocean basin. A relatively large volume of sediments is present in the Puerto-Rico Trench, appreciably less in the Cayman Trough, and very little in the South Sandwich Trench. Results reported by Raitt, Fisher and Mason show the Tonga Trench in the Pacific to be similar to the Puerto Rico and South Sandwich trenches ; more comparable to the latter in the amount of sediments present.

The island arcs are thick ridges of crustal rocks in which seismic velocities range from 4.0—5.5 km/sec in the upper part to 6.0—7.0 km/sec below depths of about 5 or 6 km. The interior basins, Caribbean Sea and Scotia Sea are similar structurally. Each is different from typical oceanic structure in that the high velocity crustal material, although having an average velocity approximately equal to that in the ocean basin areas, is thicker and consists of an upper level with velocity between 6.0 and 6.5 km/sec and a lower level with a velocity of 7.0—7.5 km/sec.

Some hypotheses of the formation of island arcs in deep sea trenches are discussed with reference to seismic, gravity and magnetic measurements.

The paper has two references, as follows :

1) *C.B. Officer, J.I. Ewing, J.F. Hennion, D.A. Harkrider,* and *D.M. Miller :* Geophysical investigations in the Eastern Caribbean : Summary of 1955 and 1956 Cruises. *Physics and Chemistry of the Earth.* Pergamon Press, Vol. III, 1959, pp. 17-109.

2) *J.I. Ewing, J. Antoine,* and *M. Ewing* : Geophysical measurements in the Western Caribbean Sea and in the Gulf of Mexico, *Journal of Geophysical Research,* Vol. 65, No. 12, 1960, pp. 4087-4126.

15. — *Dr. Talwani* reads the paper by *M. Talwani, J.L. Worzel,* and *M. Ewing* : Gravimetric studies of ocean trenches.

A detailed study of gravity profile across the Puerto Rico Trench made possible by the availability of more extensive seismic refraction coverage and the development of high speed electronic computing techniques confirms Ewing and Worzel's earlier finding that a crustal "downbuckle" is not necessary to explain the associated negative gravity anomalies. The depths to the M-discontinuity determined gravimetrically check well with seismic determinations, where the latter are available. Under the trench, the depth to M is intermediate between the shallow oceanic values to the north and the deeper values under Puerto Rico to the south.

In 1957 gravity sections were obtained on the submarine HMS Telemachus across the Tonga-Kermadec Trench. The seismic refraction structure section deduced by Raitt, Fisher, and Mason of the Scripps Institute of Oceanography was « projected » to a nearby gravity section. Assigning suitable densities to the seismic layers the gravity anomalies were computed for this section and compared with the observed values. Discrepancies of the order of 100 mgals were noted. An alternative interpretation of the seismic refraction data for the profile of Raitt and others in the Tonga Trench is suggested. This involves the introduction of a masked layer under the trench, and the depth to M under the Tonga-Kermadec Ridge to the west, for which there is no seismic control, is gravimetrically shown to be larger than that under the trench. These modifications of the seismic structure section make it compatible with the gravity observations and make its ressemblance to the Puerto Rico section more striking.

Gravimetric measurements for other trenches, including the Aleutian Trench, the Middle America Trench, and the trench along the west coast of South America, for some of which there are no seismic refraction measurements, are also discussed.

Magnetic measurements are available in profiles across several trenches. The anomalies are sharp and of large amplitude over the island or continental platforms adjacent to the trench, broader and of smaller amplitude over the ocean areas beyond the trenches, and of least amplitude and greatest breadth over the trenches. These are the effects probably to be expected from the greater depth of the layer responsible for the anomalies.

The paper has two references :

1) *M. Talwani, G. H. Sutton,* and *J. L. Worzel :* Crustal section across the Puerto Rico Trench, *Journal of Geophysical Research,* Vol. 64, No. 10, 1959, pp. 1545-1555.

2) *M. Talwani, J. L. Worzel,* and *M. Ewing* : Gravity anomalies and crustal section across the Tonga Trench, *Journal of Geophysical Research,* Vol. 66, No. 4, 1961, pp. 1265-1278.

Prof. Glangeaud, commenting on the previous papers, points out that both types of arc appear to occur in the Mediterranean.

16.— Mrs. Dr. Kosminskaya gives the paper by *P. S. Weizman, E. I. Galperin, S. M. Zverev, I P. Kosminskaya, K. M. Krakshina, G. G. Mikhota,* and *I. V. Tulina* : The structure of the Earth's crust in the region of the Kurile Island Arc.

Data obtained in 1957-1958 from deep seismic soundings, carried out according to the IGY program in the Okhotsk Sea and in the

Ocean, revealed some peculiarities in the crustal structure of ile Islands arc. Here, in distinction from the adjacent sections Okhotsk Sea and the Pacific Ocean, the crustal thickness in- and reached its maximum not under the Kurile Islands, but east of them, in the direction of the deep-water depression.

ler the eastern slope of the depression a steep rise of the vicic surface and a sharp decrease in the thickness of the saltic layer were observed.

Kurile Islands arc may be divided into three parts : southern, and northern — each of them having a different crustal ·e, apparently similar to that of its adjacent region. These are : the Hokkaido Island, the deep-water depression of the : Sea and the Kamchatka Peninsula.

: complete paper with the title "Some results of investigation seismic sounding of the crustal structure in the region of the Island Arc and in the adjoining portions of the Pacific Ocean" published in *Publications du Bureau Central Séismologique tional, Série A, Travaux Scientifiques, Fasc. No. 22.*

— *Prof. Riznichenko* reads the paper by *S. A. Fedotov, V. N. Averianova, A. M. Bagdasarova,* and *I. P. Kuzin* : Preliminary results of detailed seismic investigation of the southern Kurile Islands.

n 1958-1959 detailed seismic investigations were carried out Southern Kurile Islands, organised during the IGY by the e of Physics of the Earth and Sakhalin Scientific Complex ch Institute, the USSR Academy of Sciences.

ese investigations had been planned as part of a complex co-geophysical research in the zone of transition from the continent to the Pacific Ocean. Observations were made on ismic stations having a magnification of about 10,000 at a ncy of 1 c/sec.

In the southern zone of the Kurile Islands arc the overwhelming r of earthquakes occurred beneath the Earth's crust between the and the continental slope of the deep-water depression.

A vertical velocity section was obtained to a depth of about . It was found that the velocity V_p reached its maximum value the mantle, close to the bottom of the Earth's crust, which ·llowed by a slight decrease in velocity. In the whole depth of 0-110 km the velocity ratio Vp/Vs was about 1.74.

The disastrous Iturup earthquake of November 6, 1958 occurred upper part of the "Pacific focal plane". The region containing icenters of its aftershocks was stretched along the island arc. epths of the earthquakes increased in the direction of Iturup 0 km to 120 km.

ne paper will appear in Russian in *Izv. Acad. of Sci. USSR, Ser.* ., 1961, and in English in *Annali di Geofisica.*

18. — *Prof. Fairbridge* presents his paper on "The Me Border Plateau, a zone of crustal shearing in Pacific".

The Melanesian region, extending from eastern Australi borders of the Primeval Pacific as indicated by the "Ande is indicated by reports of earthquake and refraction seismolo semicontinental crust, of intermediate thickness, about 15 paleogeographic history seems to be exclusively late paleozoi cent, with no recognized evidence of precambrian "proto-cr

The eastern margin of the Melanesian region is the 10000 Tonga Trench, a NNE-SSW structure of typical island-arc and margin character, except that it is strikingly non-arcuate, b linear, interpreted by many as a dextral strike-slip or tran fault zone. The northern margin, in contrast, is marked by gular "border plateau" of 1000—2000 m., beyond which rathe slopes give a transition to the central Pacific basin. The top is by scattered volcanic peaks and at least 25 drowned atolls, tod 20—25 m. below the surface. The number of living coral reefs is menally small.

The Melanesian border plateau trends almost E-W but it is up into numerous NW-SE trending ridges and trenches or here interpreted as horsts and grabens produced by a sinistr couple, i.e. with the central Pacific moving relatively west an nesia to the east. Almost every trench is a closed stagnant dep the average dimensions being 200 by 15 km and 4000 m. in The recently reported "Vitiaz Trench" of Udintsev of 6149 m. i preted as the largest of this series.

The complete paper will be published in *Publications du Central Séismologique International,* Série A, Travaux Scient Fasc. No. 22.

Dr. Fraser (ICSU) asks whether North and South Islands Zealand are indeed to be differentiated as "Pacific" and "Neo- lian" respectively.

Prof. Fairbridge : Yes.

Prof. Magnitsky : In your opinion, can the process of basif convert the crust of continental type into an oceanic one, or on an intermediate type of crust as took place in Melanesia ?

Prof. Fairbridge : Regrettably I am not a sufficiently good logist or geochemist to discuss this question. However, when w sider the areal distribution of former continental crustal segm Melanesia, Indonesia, Mediterranean, Black Sea, Caribbean — it appear that "basification" or "desilicification" must be a grad process that may proceed to greater or less extent. One may p recognize every stage reflected in the seismic picture and the of each basin.

19. — *Mrs. Dr. Lubimova* reads the paper by *G.S. Gorshkov:* chemistry of volcanic rocks in connection with the f tion of island arcs.

1. Volcanic rocks of island arcs have a strongly expressed calcareous-alkali character (with a definite prevalence of Na over K), varying in composition from basalts to liparites. Towards the ocean an abrupt change of rocks is observed, intra-oceanic volcanoes eject alkali lavas with a changing composition from oceanites and nepheline basalts to phonolites and trachytes. In the direction from island arcs towards the continent, there is a gradual replacement of calcareous alkali rocks by more alkaline ones. Noticeable differences are observed already at a distance of a dozen kilometers. Intracontinental volcanoes emit already pure alkali lavas (often with a prevalence of K over Na).

2. Monotony of petrochemical features in rocks all over the island arcs, a gradual natural change in composition as the distance between the arcs and the continent increases and a sharp difference in the chemism of arcs and oceanic volcanoes are of a universal significance. These laws testify to the independence of principal petrochemical features from the variety in composition and structure of the upper layer in the Earth's crust. Volcanic foci are situated at considerable depths in the upper part of the mantle and assimilation of the crust material has a subordinated significance.

The conclusion mentioned contradicts the opinion that "Pacific» rocks, belonging to island arcs, are derivates of "Atlantic" magma contaminated in the upper parts of the crust by sialic material carried away from the adjoining continent into the sinking geosyncline. Our notions are confirmed by recent geophysical investigations in the area of island arcs. In some arcs the crust exists only directly beneath the arc and is absent not only on the oceanic side, but also in marginal seas on the continental side. Naturally, under such conditions no transportation of sialic material from the continent can occur.

3. Laws of changes in the petrochemistry of volcanic rocks are connected with a change of chemism in subcrustal substances. Rocks of intraoceanic volcanoes are considered to be "primary". Island arcs appear in places, where in the depths of the mantle powerful differentiation processes and a discharge of sialic material upwards are taking place. The lifting of immense volumes of acid sial leads to a thickening of the Earth's crust and to a replacement of "Atlantic" rocks by "Pacific" ones. Subsequently, there occurs again a slow evolution in this composition of subcrustal substance towards an increase of alkali content, and, in the continental stage of the crust, there appear alkali rocks resembling "Atlantic" rocks, however, with noticeable petrochemical differences.

Thus, volcanism is not a purely superficial or intracrustal process, but along with seismics and tectonics generally it is a superficial expression of primary subcrustal processes that determine the entire course of the Earth's development. Island arcs represent one of the indispensable links of this process.

The paper is published as follows :

1) *Bull. Vulkan. Stants.* (in Russian), No. 25, 1957.

2) *Materials to the First All-Union Conference on Geology and Metal-*

logeny of the Pacific Ore Belt (Russian abstract), Vol. 1, Vladivostok 1960, p. 98.
3) *Annali di Geofisica* (in press).

20.— Prof. Rothé presents his proposal : Séismes volcaniques, projet d'atlas de séismogrammes.

Au cours du symposium de Volcanologie tenu à Paris en septembre 1959, les membres de l'Association internationale de Volcanologie ont adopté un certain nombre de recommandations, parmi lesquelles je voudrais rappeler celle qui concerne la préparation d'un atlas d'enregistrements séismiques obtenus à l'occasion d'éruptions :

« Les participants au symposium ont insisté sur l'intérêt de l'exploitation des séismogrammes pour la prévision des éruptions. Des exemples pratiques ont été fournis concernant des volcans du type péléen (Guadeloupe 1956 ; Mérapi 1930 et 1934), de type hawaïen (Kilauea 1955 ; Mauna Loa 1942), ou de type pacifique (Kamtchatka 1955 ; Japon).

Il est apparu qu'une confrontation précise des différents types d'enregistrements séismiques obtenus dans les observatoires volcanologiques (ou dans les autres stations séismologiques) serait souhaitable et il est proposé que la prochaine assemblée générale d'Helsinki en 1960 mette à son ordre du jour la publication d'un atlas des différentes formes d'inscriptions, permettant de distinguer les séismes tectoniques locaux, volcanotectoniques et proprement volcaniques. »

Je me permets d'attirer sur cette recommandation l'attention de nos collègues séismologues et volcanologues réunis à Helsinki. Je prie ceux d'entre eux qui auraient obtenu des enregistrements caractéristiques (séismes tectoniques locaux dans les régions volcaniques, séismes volcanotectoniques, séismes proprement volcaniques) de bien vouloir adresser les originaux de ces enregistrements (ou de bonnes copies) au

Professeur J. P. *Rothé,* Bureau International de Séismologie,
38, Boulevard d'Anvers, Strasbourg, France.

Prof. Vening Meinesz : At the end of our discussions, I should wish to give my views about the reason why the island arcs get their arcuate shapes. I think that in fact the arcs consist of four straight parts, the two middle ones making angles of 55°, to both sides, with the uniaxial direction of the great size convection current in the mantle causing a drag on the crust in that direction. In these parts the Earth's crust is buckling downwards by the uniaxial compression and shows, because of the down-buckling, a belt of strong negative anomalies (over —100 mgals, going up to —200 mgals), as has been found in the Indonesian Archipelago, in the West Indian Archipelago, in the Japanese Archipelago, etc. — In the two outer parts, the island arc makes an angle of 25° to 30° with the uniaxial drag direction, as e.g. Sumatra and the Philippine Islands in the Indonesian-Philippine Archipelago. There the main crustal deformation is a horizontal slip movement along a fault plane in the directions of these islands. — Together we thus obtain the arcuate shape of the island arcs.

The session is closed.

10th SESSION

THURSDAY, JULY 28 (afternoon)

Program

1. — Scientific communications : Microseisms.

   21. — *T. A. Proskuryakova, L. N. Rykunov, E. F. Savarensky,* and *T. L. Vasilyeva* : On the influence of the relief of the Earth's surface on the propagation of microseisms.

   22. — *T. A. Santô :* Observational investigation on the origin of microseisms.

   23. — *H. Jensen :* IGY-microseisms at the station Nord.

   24. — *J. Darbyshire :* Recent research on microseisms at the National Institute of Oceanography.

   25. — *A. Zátopek :* On the nature and origin of European microseisms.

   26. — *V. N. Tabulevich* and *E. F. Savarensky :* On the question of correlation between microseisms, meteorological situation and sea roughness.

   27. — *J. N. Nanda :* The origin of microseisms.

The session is opened at 14.35 with *Sir Harold Jeffreys* in the chair.

1. — Scientific communications : Microseisms.

21. — *Dr. Rykunov* presents the paper by *T. A. Proskuryakova, L. N. Rykunov, E. F. Savarensky* and *T. L. Vasilyeva :* On the influence of the relief of the Earth's surface on the propagation of microseisms.

In recent years a number of authors have studied the influence of irregularity of the Earth's surface on the propagation of Rayleigh waves. These investigations have revealed the occurrence of distortion of wave forms and diminution of intensity of Rayleigh waves in their propagation along an uneven surface. This influence was found to be significant even when the size of the irregularity is small in comparison with the wave length.

It was noticed, that the intensity of the microseisms decreases significantly when they pass through the mountain regions.

The authors of this report previously tried to explain the amplitude peculiarities of the microseisms, which were described by some of the seismic stations of the USSR, by the influence of Scandinavian relief. A model was made for this purpose. It has some schematic elements, but the results were in qualitative accordance with the observations.

In the present work the authors have attempted to get results, quantitatively comparable with the results of the observations, by modelling the different conditions of the propagation of microseisms.

We investigated the microseisms, evoked by the cyclone on February 1-3, 1958, which moved along the north coast of Scandinavia. This choice was determined by the high intensity and localisation of the cyclone, the large pressure gradient and the strong contrary winds, as well as the relatively clear meteorological situation.

Quantities proportional to kinematic energy of the microseisms (A^2/T^2), which were obtained by some Soviet and European seismic stations, were reduced to a single distance from the source. This reduction again indicated the sharp diminution in the intensity of the microseisms, which pass over the mountain regions.

To explain the nature and extent of the influence of the relief of the Earth's surface in the path of the microseisms upon their intensity, a two-dimensional model was constructed of the real relief between the source and the stations. In the construction of the model it was assumed that :

1. the microseisms are Rayleigh waves on the granitic half space ;

2. there are no changes of the lithological composition and there are no disturbances of its continuity on the path of their propagation.

The results of model show, that the stations, for which the path of the propagation does not cross mountain ranges, gives values of the microseisms, which quantitatively agree well with observations. In the case of mountain regions a significant diminution in the intensity of microseisms is shown but this diminution is two or three times smaller than in nature (v. table).

Stations	1	2	3	4	5	6	7
Nature	1	0,75	0,75	1	0,13	0,07	0,25
Model	1	0,78	0,78	1	0,38	0,11	0,68

1 — Ashkhabad, 2 — Moscow, 3 — Makhachcala, 4 — Warsaw, 5 — Goris, 6 — Trieste, 7 — Semipalatinsk. The figures are the values proportional to the amplitudes of the microseisms.

Some of the divergence between observations and the model values for the mountain regions can obviously be attributed to the fact that in the case of the mountain regions the condition of unchanged lithological composition and unbroken rocks on the path of the microseisms which was received in constructing the model is not satisfied. We built a model which schematically took into consideration the presence of the sedimentary layers of variable thickness and almost vertical boundaries between the different rocks. Examination of this model gave a diminution in intensity of the microseisms of an order which brings into agreement the values of the model and the observations in the case of the propagation of the microseisms across the mountain regions as well.

Thus the relief of the Earth's surface has a significant influence on the propagation of the microseisms. Especially sharp diminution in the intensity of microseisms takes place, when they pass through mountain regions. In this case the diminution is determined by the relief of the surface and changes of properties of the rocks.

The complete paper will be published in Russian in *Vestnik Moskovskogo Universiteta.*

Dr. Båth : The observation of rapid amplitude decrease of microseisms when they cross mountain ranges, is interesting, as we have found the same property for continental channel waves.

22.— Prof. Wadati reads the paper by *T. A. Santô :* Observational investigation on the origin of microseisms.

During the I.G.Y. period, microseisms were observed at about fifteen stations in Japan. These data could clarify the feature of the occurrence of microseismic storms due to the passing of a cold front, a cyclone or a typhoon. In case of the first one, that is, when a cold front passes across Japan Islands from west to east, a microseismic storm occurs almost at the same time at every station, whereas in case of the second or the third one, the microseismic storm shifts according to the running of the cyclonic center. Besides, when the disturbance source is a cyclone or a typhoon, the relation between the occurrence of microseismic storm at a certain district on land and the travelling of the source is quite similar to that between the arrival of the "bow wave" and the travelling of a ship whose speed exceeds the group velocity of the wave.

In order to check this analogy, the data of swells near a station are used. Further, the observational facts concerning the distribution of swells around the cyclonic center are considered and it is found that this analogy is quite suitable. The periods of microseisms are approximately equal to half the period of swells.

These facts lead us to the conclusion that the energy of swells may be transferred to the earth somewhere in the littoral zone by the standing waves due to some interfering phenomena.

Recent papers on microseisms by *T. A. Santô* have the following references :

1) *Bull. Earthquake Research Institute,* Vol. 37, 1959, pp. 307-325.

2) *Bull. Earthquake Research Institute,* Vol. 37, 1959, pp. 483-494.

3) *Bull. Earthquake Research Institute,* Vol. 38, 1960, pp. 241-254.

Sir Harold Jeffreys : I should say at this point that I know of four theories of the origin of microseisms. The first is Longuet-Higgins' theory that they are due to second-order variations of pressure on the sea bottom. The second is that they are due to waves breaking on the shore and sending out elastic waves. The third is that they are due to wind shaking buildings and trees. The fourth is that they are man-made, mainly due to traffic. I think that each of these hypotheses is the right explanation of some microseisms. Perhaps somebody can tell me if this statement of the position is correct.

Dr. Båth : It would be desirable, as the Chairman proposes, to be able to exclude one or several of the proposed explanations for microseisms. However, this is not universally possible, as the microseismic conditions may be totally different in different regions. Moreover, more than one cause may be effective in a given place.

Dr. Deacon : Please can I make a small amendment to the Chairman's implication that Dr. Longuet-Higgins' theory provides for the generation of microseisms in deep water only. He shows that when waves approach a coast they can be partially reflected and produce a standing-wave component in shallow water. His theory shows that this, as well as wave interference over deep water, can account for observed ground oscillations.

Mr. F. W. Lee : The records of T. A. Santô's paper clearly show a heterodyne frequency of two periods, which have not been evaluated.

Father Lynch asks whether the author implied that a cyclone could not be detected when far out at sea (by seismic ground waves).

Prof. Wadati replies that not enough data was available for such a sweeping statement but that on the basis of time measurements, those cyclones studied were only recorded when they had reached shore.

23. — *Mr. Jensen* gives his paper on "IGY-microseisms at the station Nord".

Le service séismique fonctionnant à la station météorologique Nord sur la côte nord-est du Groenland (81° 36'N, 16° 40'W) fut établi par l'Institut Géodésique du Danemark le 1er septembre 1957. L'appareillage se compose d'un séismographe Strobach N-et-E ($T =$ 6 sec., $V_0 = 500$), prêté par l'Université de Hambourg, et d'un séismographe Willmore Z à courte période ($Tp = 1$ sec., $Tg = \frac{1}{4}$ sec. $V\max = 30\,000$). Les instruments sont installés sur un pilier de 4 m en ciment armé scellé sur le roc et pénétrant dans un sol glacé en permanence. Au-dessus du pilier est placé un petit observatoire bien isolé, réchauffé à l'électricité. L'agitation microséismique pour la période du 1er septembre 1957 au 31 décembre 1958 a été mesurée toutes les 6 heures. Voici le résumé des résultats :

Amplitude et période présentent une variation annuelle correspondant à ce qu'on connaît aux autres stations sur l'hémisphère boréal. Les moyennes mensuelles des amplitudes à la station Nord sont le tiers environ des moyennes mensuelles correspondantes au Scoresbysund, situé à environ 1100 km plus au sud sur la côte est du Groenland. Une tempête microséismique à la station Nord coïncide toujours avec une tempête microséismique à Scoresbysund — mais l'inverse ne se produit pas.

Les microséismes en groupes n'apparaissent pas être un phénomène d'hiver spécial, comme c'est le cas au Scoresbysund et à Ivigtut et en partie aussi à Copenhague.

La direction d'approche peut être déterminée lorsque l'amplitude de l'agitation de 6 secondes est assez grande pour être enregistrée sur Z. Par conséquent, le matériel présenté ne comprend pas les mois d'été. La direction d'approche la plus fréquente est le sud-ouest avec une période moyenne de 5.9 sec.; à partir de cette direction la fréquence diminue des deux côtés. Le nord-ouest a une période moyenne de 4.7 sec. Les directions nord, nord-est, est et sud-est n'apparaissent pratiquement jamais.

Conclusions: 1. Aucune agitation séismique ne se produit dans les parties du Bassin polaire profond.

2. L'agitation à périodes relativement courtes venant du nord-ouest peut prendre naissance dans la région côtière ou sur le "shelf" groenlandais ou canadien.

3. Le Bassin polaire, étant de structure océanique, aura un effet modérateur sur l'agitation, de sorte que la naissance d'une agitation au nord de l'Asie ne peut être mise hors de question.

4. La région qui produit la plus grande partie de l'agitation enregistrée à København, doit se trouver sensiblement plus proche de la côte norvégienne que de la côte groenlandaise.

5. Le « continent » groenlandais ne modère pas sensiblement l'agitation.

6. Le secteur d'où vient la plus grande partie de l'agitation enregistrée à la station Nord, comprend la partie sud de la côte ouest du Groenland. Celle-ci est la seule partie de la côte groenlandaise qui ne soit pas bloquée par des glaces pendant l'hiver.

The paper has been published in *Geod. Inst. Medd.* No. 39, Copenhagen, 1961. Earlier papers by *H. Jensen* on microseisms have appeared in the same series : No. 34, 1957, 27 pp.; No. 36, 1958, 18 pp.; No. 38, 1959, 23 pp.

24.— Dr. J. Darbyshire gives his paper on "Recent research on microseisms at the National Institute of Oceanography".

A seismograph station has been set up at the National Institute of Oceanography, Wormley, England, with the primary object of studying microseisms. Electronic seismographs designed by Tucker are used. They have a flat response from 1 to 10 sec. wave-period and a maximum magnification of 18,000. Briefly the principle of the horizontal seismograph is that it consists of a pendulum of 1.6 sec. natural period with a coil attached to the bob. The displacement of the bob relative to its mean position is measured by a transducer and the output of this is amplified and fed back with an appropriate phase correction to the coil on the bob. By this means the characteristics of the pendulum are mainly determined by the constants of the electrical circuit. In the latest models, the two horizontal components are measured by the same instrument by using two transducers on one pendulum. The vertical seismograph is similar in principle but here the pendulum is arrested in a horizontal position by a "zero-length" spring.

The output of these seismographs are recorded on pen-recorders and during the period October 1957 to August 1958, there were 19 occasions when the maximum amplitude exceeded 5 microns for a period of about 4 days. The maximum amplitude, the wave-period corresponding to it, and the storm centre pressures in the North Atlantic Ocean were plotted together and it was apparent that increase in microseismic activity could be attributed to four main causes.

1. Intensification of a fast moving storm.
2. Rapid approach of an intense storm.
3. The passage of a storm into an area where refraction effects cause focussing of the waves towards Southern England.
4. The effect of swell reaching the coasts of the British Isles.

Some examples of these effects are given.

It has been shown that the direction of approach of storms can be calculated from the correlation coefficients between the three components. Calculation of these is normally a lengthy process but simple instruments have been designed which do this automatically and also measure the r.m.s. displacements and mean periods. The winter of 1959-60 has been studied with the aid of these instruments. The month of December was very stormy and the microseismic amplitudes and periods were related to the sea-wave heights and periods observed at weather-ship station "Juliett" (52°30'N, 20°00'W).

During the winter period, there were several isolated storms which were suitable examples for tracking by microseisms. One in January was tracked and the results are shown, allowance being made for the effect of refraction of microseisms. Another storm in April was also tracked and in this case results from two stations, one at Wormley and one at Herstmonceux were used.

The work shows the usefulness of the study of microseisms for storm prediction and tracking.

The complete paper will be published in *Research Applied to Industry* (A British publication).

Mr. Jensen : How much time do you need for making a single direction-determination ?

Dr. Darbyshire : About two hours, but a long record is usually analysed at once and it would not take much more time to do 10 or 12 as one.

Dr. Deacon : I cannot add anything useful to what Dr. Darbyshire has said, but I hope with him that the modern, fairly simple apparatus makes detailed study of specific "storms" relatively easy.

Prof. Zátopek : Were all storms during the period in consideration analysed in the described way ?

Dr. Darbyshire : All storms are analysed as a matter of routine but the results for all the storms have not yet been worked out.

Dr. Stoneley : I am glad that Dr. Darbyshire has been able to take account of the refraction of the microseismic waves following changes in the depth of the ocean. I now have available a set of calculations of Rayleigh wave velocities for more realistic models of the ocean floor. Unfortunately, I fear this means more hard work for Dr. Darbyshire.

25.— Prof. Zátopek gives his paper : On the nature and origin of European microseisms.

General characteristics of European microseisms in the period range from 3 to 9 seconds were the subject of investigation. A continuous analysis of amplitudes and periods of microseisms in relation with synoptical factors at 0^h, 6^h, 12^h and 18^h GMT and additional parameters has been carried out at the seismological station of Praha (50°04'.2 N, 14°26'.0 E) since 1948. Comparisons of results obtained were made for more than 15 European stations; especially the periods of activity during the IGY and IGC were considered. Earlier results of Gutenberg, Båth and others were confirmed, completed and generalised.

The common character of microseisms observed at the seismological stations in Europe appears to be dominated by the cyclonic activity in the eastern part of the frontal zone between the eastern coast of North America and the western coast of Europe, mainly in the area situated north of 50°N and east of 40°W. In this region the most important sources of microseisms occur in connection with the development and movement of intense cyclones passing over the open ocean roughly from west to east. Microseisms provoked by these sources "of first order" are propagated through the European continent and can still be stated in records of seismological stations in SE-Europe, e. g. that of Athens. These microseisms are often superimposed by oscillations coming from nearer sources "of second order" which are responsible for regional particularities of microseisms and appear rather in the vicinity of the coast. The latter effects due to secondary barometric lows, coastal winds, cold front passages from the sea to the land and the surf may be very strong at coastal stations and are observed at varying distances from the source and from the coast; geological conditions are of a great importance. In this way some discrepancies in results of various stations can be explained. On the contrary, the continental disturbances in well protected vaults are negligible.

Using idealised sum curves of amplitudes the general character of microseismic activity may be derived for various active periods and for individual stations. For a given period of activity the fundamental shape of adjusted amplitude curves remains similar for different stations. This is a clear evidence for a close relation of the microseismic activity with the atmospheric circulation in the frontal zone mentioned above. An index number connected with the west-east component of circulation in the isobaric surface of 500 mb. shows a similar general course like that of microseismic amplitudes.

The complexity of microseisms indicates that they are generated in different ways. Their origin on the open ocean may be explained by pressure variations transferred to the sea bottom from the surface according to the theory of Longuet-Higgins. This conclusion seems to be supported by the passive behaviour of most stationary cyclones. Standing waves may also produce microseisms in closed basins, e. g. in the Baltic Sea. A part of microseisms originated in coastal areas can be immediately attributed to the surf effect.

Correlating positions of barometric low centers in the Atlantic with amplitudes in Central Europe, where the coastal effects may be neglected, one obtains by higher frequency numbers a statistical information on the position of the origin regions. For the station of Praha it was found that there exists a preference of oceanic depths in the range from 1000 to 3000 meters.

The complete paper has been published in French in *Studia geophysica et geodaetica,* Vol. 5, No. 1, 1961, pp. 51-63. Recent papers of related content by A. Zátopek have appeared in the following publications :

1) *Studia geophysica et geodaetica,* Vol. 4, No. 3, 1960, pp. 233-249.

2) *Freiberger Forschungshefte,* C 81, 1960, pp. 171-186 (together with O. Zikmunda).

Mr. Jensen : In Copenhagen we have found that the "Grosswetterlage" HM — "Hoch Mitteleuropa" — favours a direction of approach of the microseisms from the north, which the other usual situation in the 500 mb surface, Wz — "zyklonale Westlage" — does not. Am I right to say that this fact fits your point of view as regards the polar air ?

Prof. Zátopek : Certainly. The impacts of the polar air are of the greatest importance for generation of microseisms in our zone.

26. — *Mme Dr. Proskuryakova* reads the paper by *V. N. Tabulevich* and *E. F. Savarensky :* On the question of correlation between microseisms, meteorological situation and sea roughness.

As was established by theory (Longuet-Higgins) and practice the occurrence of microseisms is caused by sea roughness of a stamp type (standing waves) which in its turn takes place as the result of wave convergence in the open ocean or reflection of waves from the shore. However, the attempts to analyse the microseisms ended in failure to obtain distinct results. The location of the cyclones by the method of tripartite stations cannot be regarded as ideal in essence. Cases are met when microseisms in a given point are the result of the composition of processes propagating from different sources, having different frequencies and caused by different factors. Besides, the source of excitation can be of a complex character which makes difficult the location of the source by three momentary values of the soil displacement in points separated by space. In addition the conditions of receiving oscillations in the points can be different.

The ultimate end of the present work is the development of a method which would make it possible to distinguish from the total number of microseisms those emitted by the same source and locate the latter.

Conclusions : The investigation of microseisms is impossible without revealing the frequency synchronization in different points of observation. The proposed method was used to locate cyclones in the Caspian Sea, Atlantic and Pacific Oceans, where the source coincided with the rear part of the cyclone.

The paper has been published in Russian in *Izv. Acad. Sci. USSR, Ser. Geofiz.,* No. 11, 1959, p. 1694.

Dr. Deacon : I hope that perhaps the contributions of the last two speakers may have convinced the Chairman that it is the waves in oceans and seas that produce microseisms of the first order, and that those produced by the impact of waves, wind in trees and traffic are generally of the 2nd, 3rd or 4th order. I work in a laboratory on the top of a hill in Surrey and the background is usually quiet, but when there is a storm over the ocean to the westward, the recorder pens move very actively backwards and forwards across the record and one has only to draw the curtains and look at the recorder to feel very much at sea. — I hope too they will attract more interest. They have been unpopular at Cambridge ever since they prevented G. H. Darwin and his brother from measuring the tide-raising force by the deflection of a pendulum. But we have now a lot of interesting information about their origin and it is not inconceivable that the changes in amplitude, and the changes in the ratio of Rayleigh wave to Love wave components, as they travel across the oceans and continents, may provide a useful tool for studying the upper part of the Earth's crust.

Mr. Figueroa raises the question of the influence of soil conditions on the amplitudes of microseisms.

Dr. Longuet-Higgins, in reply, refers to the work of A. W. Lee.

Dr. Shebalin : The soil conditions must be taken into consideration using the method of Tabulevich, but as a first approximation this is not necessary, because the first result shows that the circle crossings from different stations give the best agreement when in the relation $\frac{n_1}{A_1} / \frac{n_2}{A_2} = \frac{d_2}{d_1} = k$ we supposed $n_1 = n_2 = 1$, without any corrections for soil conditions. Nevertheless, some stations give in every case bad crossings, perhaps due to their rather different soil conditions.

27.— J. N. Nanda : The origin of microseisms. This paper was presented by *Dr. Nanda* at the end of the 5th Session, but is included here.

The origin of microseisms is clouded with a lot of controversy. It is only recently that the technique of locating the source by means of correlation of vertical and horizontal components of ground motion has been perfected. By such direction finding techniques, workers in U. K. have located the area of the origin of microseisms to be under storms over the deep ocean. Microseismic intensities are often correlated with surf action near coastline; but such observations include widely different amplitudes for almost identical surf conditions. Microseisms seem to increase in intensity considerably when a storm moves over the continental shelf from the deep ocean, and the intensity ceases when the storm steps over land from the sea. The magnification of the seismographs is also not ample at some of the observatories reporting microseisms and failures on this account to record the relatively feeble microseisms due to storms over the deep ocean have resulted in claims regarding existence of microseismic barriers. All such failures are not likely to be due to barriers.

In 1950 M. S. Longuet-Higgins gave a mathematical theory for generation of microseisms on account of wide-spread in-phase pressure oscillations beneath standing waves as first derived by Miche.

According to M. S. Longuet-Higgins theory, the groups of waves moving in opposite directions generated by storms or by wave action on coastline give standing waves. The Longuet-Higgins theory does not involve directly the depth of the ocean (except for certain resonance effects). The theory also nicely gives the relation that the frequency of the microseisms will be double that of sea waves giving rise to standing waves. At present there are the following criticisms against this standing wave theory (See at the foot of this page).

The supporters of the standing wave theory do not have any real answer to the criticisms (a) and (d); but regarding (b) and (c) they maintain that all observations which go contrary to the theory, are made with inadequate instrumentation and simultaneous recording of microseisms and sea waves is not done.

In this paper there is no evidence in support of criticisms (b) and (c) above. But we have considered an alternative origin which may be acceptable in case irrefutable evidence is forthcoming in connection with the criticisms (a) and (d). The alternative origin is the action of suitably oriented winds with rough sea surface. The author has earlier described that sea roughness has got certain periodicity. Such periodicity can arise on account of existence of standing waves but it can also arise in different ways ; for example the amplitude of the progressive waves might be a periodic function of time, the period being the same as the period of the corresponding microseisms. In such a case the interaction of convergent winds under a storm or of winds parallel to coastline will bring about oscillations in the sea surface which will be transmitted through the ground as microseisms. The order of this wide-spread pressure term will be the same as the Miche term of M. S. Longuet-Higgins' theory, if we recognize periodicity of sea roughness to be caused in the second manner. In case the periodicity is due to standing waves then, of course, the interaction term is much less than the Miche term and the Longuet-Higgins' theory alone can give rise to observed microseismic amplitudes. To sort out the controversy, further effort should be made in understanding the origin of the observed periodicity in the sea roughness or, in other words, in attempting to observe standing waves on the ocean surface.

a) Existence of standing waves in the ocean may just be a mathematical fiction. There has been no independent way to check this by observation.

b) Similar surf conditions should give rise to similar waves and, therefore, similar microseisms, but actually this is not so.

c) The frequency relationship with the sea waves is not such an established fact.

d) The order of microseismic amplitude is quite different, when the storm is over the shelf than when over the deep sea. According to standing-wave concept, no such increase is called for.

The paper has been published in the *Journal of Geophysical Research,* Vol. 65, No. 6, 1960, pp. 1815-1820.

The session is closed at 16.55.

11th SESSION

FRIDAY, JULY 29 (morning)

Program

1. — Scientific communications : Constitution of the Continental and Oceanic Crust.

28. — *B. P. Bogert* and *Tuke :* Analysis of seismic waves.

29. — *M. Båth :* The question of internal layering in the continental crust.

30. — *P. L. Willmore* and *A. M. Bancroft :* The time-term approach to refraction seismology.

31. — *G. K. Tvaltvadze :* Study of the Earth's crust on the basis of the data of near earthquakes.

32. — *A. A. Treskov :* Teleseismic determinations of the Earth's crust thickness.

33. — *L. Migaux, J. L. Astier* et *Ph. Revol :* Essai de détermination expérimentale de la résistivité électrique des couches profondes de l'écorce terrestre.

34. — *G. P. Woollard, C. Bentley,* and *E. C. Thiel :* Crustal structure and warping in Antarctica as deduced from gravity and seismic observations.

35. — *S. B. Treves :* Structural implications of American geological work in Antarctica during the IGY.

36. — *L. Ponce* : Preliminary gravity results on the Deception Island.

37. — *J. N. Nanda :* Evaluation of average crustal characteristics from reverberation of seismic waves.

The session is opened at 9.05 with *Sir Harold Jeffreys* as chairman.

1. — Scientific communications : Constitution of the Continental and Oceanic Crust.

28. — *Dr. Bogert* presents the paper by *B. P. Bogert* and *Tuke :* Analysis of seismic waves.

No abstract or reference is available for this paper.

Prof. Press : In the results of Benioff, Press, and Smith the free oscillations were recorded on a Benioff strain seismograph with excellent long-period response *(Journal of Geophys. Res.,* Feb. 1961). Your instrument was a relatively short-period pendulum. Do you think you could use numerical-digital methods to recover the lowest free modes even if their amplitudes are below the noise level ?

Dr. Bogert : This may be possible if the instrumental noise is not excessive. We will try this method.

Prof. Hales : Would you sketch for us the overall response curve of your system ?

Dr. Bogert explains with a diagram that the amplitude response taking into account the properties of the seismometer and the amplifier was approximately flat from 12 sec to 60 sec and thereafter fell off as $1/T$.

29. — *Dr. Båth* gives his paper : The question of internal layering in the continental crust.

All seismologists agree about the existence of a sharp lower boundary of the crust — the Mohorovičić discontinuity, whereas the opinions diverge considerably with regard to the internal layering of the continental crust, i. e. the existence of the Conrad discontinuity. While many scientists are convinced about the existence of a sharp Conrad discontinuity, others deny its existence or believe in a gradual instead of a discontinuous increase of velocity with depth in the crust. A review is given of all available determinations of continental crustal structure by seismic explosion methods, and various difficulties in the determination of the internal layering are emphasized. In general the velocity seems to be increasing downwards in the crust and a Conrad layer seems to exist. The divergences of the results are almost exclusively due to the interpretation of the records and the travel-time plots, and the observations do not justify the conclusion that different continents have different structures. There may be minor differences, as variations in the vertical velocity gradient, but the observations are still inconclusive on this point.

A proposal is made for an intensified international cooperation in order to solve the problem of the internal layering of the continental crust, a problem which has extensive geophysical implications.

The complete paper will be published in German under the title "Die Conrad-Diskontinuität" by the Bergakademie, Freiberg, Sachsen, Germany-DDR (*Freiberger Forschungshefte,* C. 101, 1961).

Sir Harold Jeffreys : Dr. Båth's paper is very important and recalls me of Miss Lehmann in the Geophysical Supplement in the 1930's. I thought in 1926 that I had verified Conrad's P* and found the corresponding S* in the Jersey earthquake *(Month. Not. Roy. Astr. Soc., Geophys. Suppl.,* Vol. 1, 1926, pp. 385-402), but as other studies failed to verify them I became doubtful. The Japanese reports in the ISS sometimes gave many observations that appeared to fit P* and S*, but Lapwood made a special examination of these and found no evidence of anything but accidental alignments (*Month. Not. Roy. Astr. Soc., Geophys. Suppl.,* Vol. 7, No. 3, 1955, pp. 135-146). Dr. Båth mentioned that we can always draw a straight line between two points. It is also true that if we have three points between the Pg and Pn waves we will also usually be able to draw a straight line somewhere near them. — In a discussion Dr. M. N. Hill called attention to a systematic error that can arise when only first arrivals are used. If there is doubt where the faster pulse enters, it is possible through random error that a reading belonging to the slower pulse before the overtake may be referred to the indirect one, and will lead to an underestimate of the speed of the indirect wave. On the other hand, one belonging to the indirect wave after the overtake may be referred to the direct one and will give an underestimate of *its* velocity. My recommendation would be "In case of doubt, leave it out". The standard error becomes larger but there is less risk of a mistake.

Prof. Hales : The subject of Dr. Båth's paper is one of great interest to me. I do not know whether there are differences between the average structure between one continent and another. Such differences can, it would seem, be found only by group velocity or phase velocity studies such as those made at Lamont. However, I think there is good evidence of difference in crustal composition between different parts of the same continent. I have recently spent some time at Department of Terrestrial Magnetism, Washington, D.C., looking at the records made by Drs Tuve, Tatel and their associates. Dr. Asada was there at the same time and we agreed that there are differences in structure at different places. The best example of this comes from Montana, where Dr. Aldrich, working with the University of Wisconsin group, finds clear evidence of an intermediate phase as a first arrival. In so far as the differences in the interpretation of Transvaal records are concerned, I should point out that the differences depend on whether one makes use of second arrivals or not. In order to identify these second arrivals more easily the technique used by the University of Wisconsin group of arrays of seismometers and very closely spaced observations is a great deal better than single seismometer observations. — The Department of Terrestrial Magnetism group has recently done some experiments on the use of comparatively simple arrays to improve the quality of near-vertical reflections by reducing the short wave-length arrivals such as P and Rayleigh waves relatively to the very long wave length near vertical reflections.

Dr. Willmore : It is possible to obtain an estimate of the thickness and average velocity in the crust if one has good estimates of the slope and intercept of the Pn curve, together with normal reflection from the Moho, or an estimate of the distance from the source at which the critical reflection reaches the surface. In the Transvaal, this method showed that the average velocity in the crust was higher than the velocity of Pl, but there were local exposures of high-velocity material which confused the picture. In Eastern Canada, the average velocity found by Hodgson was not significantly higher than that of Pl, but in Alberta there is evidence of higher velocities in the lower part of the crust. — We also have a valuable, but incomplete body of data from the Heligoland explosion, in which two profiles covering the range of about 50-100 km from the source both showed velocities higher than those expected for Pg. These were variously interpreted as P* or as Pg observed in regions where the basement was rising towards the surface with increasing distance from Heligoland. However, one of the controversial profiles ran through Schleswig-Holstein, and the ambiguity could be resolved if the stations were to be re-occupied, and reversed observations obtained from shots in the Baltic.

Dr. Meyer : Currently there is work progressing which makes use of the additional criterion that the solutions based on any particular refraction model have also to produce reflections (especially critical reflections) at corresponding calculated ranges and times. In particular the existence of arrivals at the critical point predicted is used for a criterion to accept or reject a refraction model. — Other studies pertinent to the same question are : 1) The effects of the omission of the low-velocity layers in the solution and the error produced in the case of the single-ended profile are quite different, depending on the method of computation. 2) The uncertainty in velocity and depth, due to the lack of fit of the lines to the points on the travel-time plot for any particular model, is currently being evaluated in terms of confidence limits. This gives an evaluation of the uncertainty which is known to exist and hence gives a criterion which allows an evaluation of the question which your paper has raised, i. e. are crustal measurements truely different ? — The question of the existence of gradients in the crust is one which we hope to resolve through the use of amplitude information. We already found real evidence for gradients, for the amplitude change which we observe with increasing range is too small to be accounted for by conventional head or refracted wave theory.

Prof. Riznichenko : Dr. Båth has expressed quite sound considerations. — I am sure that a simple comparison of the results obtained by various methods in the same region may lead to the opinion that the Earth's continental crust is the same in every case or that it is impossible to say anything about the variations in the structure of the crust between various regions. — It would be unfair to compare two results, one obtained by a good method and another by a bad one and to say that both are insufficient to derive any definite conclusions. — The USSR seismologists study not only travel-time relations but also amplitudes. They are sure that the Earth's crust has different structure in different regions and perhaps even in different parts of the same region. Some details in this respect will be described in papers by our colleagues presented at this Assembly.

Prof. Bullen : In another context, I have been doing mathematical work on a velocity law of the form $v = v_0 r^x$, with reference to a layered Earth. This law has greater flexibility than taking v constant in a layer, and includes the latter ; also it is remarkably simple in some of its mathematical properties. It is adaptable to some cases of "channel waves", and throws important light on some amplitude questions, and on cusps in travel-time curves. It shows that amplitudes can be sharply affected even by changes in d^2v/dr^2, and underlines the care needed in seeking to interpret amplitude data. My interest in this work has been mainly related to the Earth's deeper interior, but the work may well be of assistance towards helping to resolve some of the crustal problems which Dr. Båth has drawn attention to.

Mrs. Dr. Kosminskaya : The interpretation of the times of the first, second, and so on arrivals is not sufficient to derive any definite conclusions. Amplitudes of the waves, their periods and their attenuation must also be studied. — The most complicated question is that of the physical nature of the waves observed. -- According to the USSR field experiments, calculations, and model studies, the rôle of reflected waves in the refraction type seismogram is sometimes very important. These waves have to be carefully examined, as it is possible to make mistakes in distinguishing between the refracted waves from the Conrad discontinuity and the over-critical reflections from the Moho. — There may be cases where the kinematic study gives no possibility to distinguish the type of waves. This question *may* be solved by means of a dynamical study.

Prof. Egyed : The Hungarian data shown by Dr. Båth are the results of deep reflections. But also refraction measurements with reverse shooting have been carried out in eastern Hungary, and the data are consistent with the results of the reflection measurements. The profile was about 150 km long.

Dr. Bott : Is there any evidence from crustal refraction work, as at present known, which is incompatible with the existence of a low-velocity layer within the crust ?

Dr. Båth : No. The difficulty is that no ray can have its deepest point in a low-velocity layer.

Prof. Byerly : My views have been set forth in *Advances in Geophysics,* Vol. 3, 1956, pp. 105-152, and they agree with Dr. Båth.

30.— Dr. Willmore presents the paper by *P. L. Willmore* and *A. M. Bancroft :* The time-term approach to refraction seismology.

In all seismic refraction surveys, the problem is to determine the constants in a system of equations of the type

$$t_{ij} = a_i + b_j + \Delta_{ij}/v$$

where a_i and b_j are "time terms" which are characteristic of the shot-point and seismograph station respectively, Δ_{ij} is the distance between the shot-point and the seismograph, t_{ij} is the time of propagation of a refracted wave and v is the velocity of propagation of seismic waves in an underlying marker layer. It is shown that the equations can be solved for interpenetrating networks of shot-points and seismographs provided that certain general conditions are satisfied. Factors which determine the uncertainties of the final solution are discussed, and methods of correcting for the effects of steeply dipping boundaries are included.

The paper has appeared in the *Geophysical Journal*, Vol. 3, No. 4, 1960, pp. 419-432.

31. — *Prof. Riznichenko* reads the paper by *G. K. Tvaltvadze:* Study of the Earth's crust on the basis of the data of near earthquakes.

Utilization of records of near earthquakes for the study of the Earth's crustal structure is of definite significance, for earthquakes, in the main, occur in mountainous regions which offer little opportunity for other methods of investigations.

It is with this object in view that the present study has been made of the data on an earthquake of relatively high intensity, as recorded at a number of stations situated at various distances from the epicentre.

$S - P = \Delta t$ is measured for all waves ; coordinates of the epicentre and the depth of the hypocentre are determined ; curves for travel-time differences are constructed and the corresponding equations given for each of these travel-time curves.

The Earth's crust is assumed to be composed of three layers : sedimentary, granitic, and basaltic.

a) It is first assumed that the hypocentre is located in the first layer. We then obtain four branches of the travel-time curve corresponding to : $S_1 - P_1$, $S_{12} - P_{12}$, $S_{13} - P_{13}$, $S_{14} - P_{14}$. The inverse values of the angular coefficients of these branches have velocity dimension. We call them fictitious velocities and designate them V^f :

$$V_1^f = d\Delta/(d\Delta t_1), \quad V_2^f = d\Delta/d(\Delta t_2), \quad \text{etc.}$$

Formulae are given for the determination of the layer thicknesses in this case.

b) When the earthquake focus is located in the second layer the first two layers have to be regarded as a single layer with a total thickness of $H_1 + H_2 = H_{1+2}$, while thicknesses H_{1+2} and H_3 are determined from formulae given in the paper.

c) If the focus is located in the third layer the entire crust has to be regarded as a single layer and one can succeed only in determining the total thickness of the entire crust, for which formulae are given.

The results of calculations by the method are in fair agreement with the results of layer-thickness determinations of the Earth's crust by the method of deep seismic sounding, and with the results of quantitative interpretation of gravity anomalies.

The full paper will be published in *Publications du Bureau Central Séismologique International,* Série A, Trav. Sci., Fasc. No. 22.

32. — *Prof. Treskov* presents his paper : Teleseismic determinations of the Earth's crust thickness. The presentation is in Russian, and a summary is given in English.

In 1947 the author developed a teleseismic method of determining the thickness of the Earth's crust from observations of waves reflected from its lower boundary. The same reflections were discovered independently by E. Vesanen (*Ann. Acad. Sci. Fenn., Ser. A, III. Geol.-Geograph.,* 14, pp. 3-19), and by M. A. Choudhury (*Annales de Géophysique,* Vol. 14, No. 1, 1958, pp. 31-75).

By the Choudhury scheme the crust thickness is determined as the depth of a fictitious focus for which the difference pP-P coincides with pP-pP^x where phase pP^x corresponds to a wave reflected from the lower boundary of the crust.

The major inaccuracy of the Choudhury method lies in the fact that it does not take into account the increase of the travel time when the wave propagates in the crust's layer between its local boundary and a boundary fit for the Jeffreys model.

The use of the Jeffreys travel time table for determining the crust thickness requires that the computations be carried out by comparing the local thickness of the crust with the crust thickness from the Jeffreys model. This demand is met in the Treskov formula :

$$H = 33 \frac{\frac{pP\text{-}pP^x}{2}}{Tp - Tp^0} \text{ km}$$

where 33 km is the Earth's crust thickness by Jeffreys, T_p — travel time with the focus on the surface and Tp^o — with the focus at a level of 0.00.

The Earth's crust thickness as determined from the data of the Hindu-Kush earthquake on March 4, 1949, is 57 km by Treskov and 77 km - by Choudhury. However, as the thickness varies within 30—40 km, both methods yield practically identical results. Teleseismic determinations of the Earth's crust thickness in Japan agree well with those obtained by the Japanese seismologists from observations of near earthquakes.

The full paper will appear in *Publications du Bureau Central Séismologique International, Série A, Trav. Sci., Fasc. No. 22.*

Sir Harold Jeffreys : Reflexions on the under side of the Moho would give most valuable information on the thickness of the crust. I tried to use these once, but on examining records of deep earthquakes in my possession I could find nothing readable that admitted this interpretation. The records shown by Dr. Treskov do however show a quite definite pulse. — I derived an equation for deep-focus by comparing the times of pP with those calculated from P on the hypothesis of given thicknesses of the surface layers, and this was used as one of the equations of condition for corrections to the thicknesses. Agreement between different sets of data was however not perfect, and in particular there seemed to be a systematic difference between the results derived by comparing pP with P and those found by comparing sS with S.

Prof. Riznichenko, in reply to a question by *Prof. Press,* says : I do not know of any determinations of the thickness of the crust in Georgia by means of the phase-velocity method. As far as I know, a comparison of Tvaltvadze's results can only be made with those of deep seismic sounding. In Georgia only studies of the group velocities of R and L waves have been made, which are insufficient for any local conclusions.

33. — *Dr. Migaux* presents the paper by *L. Migaux, J. L. Astier* et *Ph. Revol :* Essai de détermination expérimentale de la résistivité électrique des couches profondes de l'écorce terrestre.

Les possibilités de détermination directe de la résistivité de l'écorce sont le plus souvent limitées à des profondeurs de quelques kilomètres, qu'il s'agisse de mesures dans les forages ou de mesures à partir de la surface par le procédé classique du « Sondage électrique ».

Cependant, la mise en œuvre de moyens plus importants et l'amélioration des mesures ont permis d'accroître la profondeur d'investigation au cours d'un grand sondage électrique exécuté en Vendée sur le massif granitique de *Mortagne*. L'écartement des prises d'envoi de courant a atteint 70 km. Il est proposé une interprétation du diagramme obtenu.

Sous 250 mètres à 250 ohms.m., on rencontrerait d'abord une épaisseur de 7.000 mètres à 1.400 ohms.m., puis un terrain à résistance verticale très élevée, par exemple 25 km à 16.000 ohms.m. ou 8 km à 50.000 ohms.m. Celui-ci serait suivi d'un milieu beaucoup plus conducteur.

Pour expliquer ces résistivités élevées, il faudrait admettre que l'augmentation de conductibilité due à l'accroissement de la température en profondeur, est compensée par une diminution de la proportion d'électrolyte dans les roches.

The paper will be published in the *Annales de Géophysique.*

34. — *Prof. Woollard* gives the paper by *G. P. Woollard, C. Bentley,* and *E. C. Thiel :* Crustal structure and warping in Antarctica as deduced from gravity and seismic observations.

Results of the IGY program in gravity and seismic measurements of ice thickness in Antarctica make it possible to deduce both the thickness of the crust and the probable amount of crustal warping that has been occasioned by the load of ice. The results suggest that although much of Western Antarctica was an island archipelago prior to being covered by the present ice cap, the area as a whole is characterized by a continental type crust varying in thickness from about 28 kms to over 40 kms. The amount of crustal warping appears to have been of the order of 1 km.

35. — *Dr. Treves* presents his paper : Structural implications of American geological work in Antarctica during the IGY.

During the IGY parties from the United States investigated the geology of the Windmill Islands, Dufek Massif, Mt. Takahe, Horlick Mountains, Mt. Johns, Mt. Ewing, nunataks near the Sentinel Mountains, and nunataks in the Antarctic "graben". This new information is the basis of the following interpretations.

The stratigraphy and structure of the Queen Maud Range are similar to those of the Horlik Mountains and the Dufek Massif. The mountains are probably genetically related and an extension of the

Queen Maud Range. The trend can probably be further extended to include the Theron and Shackleton Ranges.

Nunataks which consist of granitic and metasedimentary rocks are present well within the boundaries of the Antarctic "graben". These rocks, however, are unfossiliferous and do not appear to be Beacon equivalents, which might be expected here if this area were part of a graben. The rocks may well be Precambrian in age and possibly are Robertson Bay equivalents.

Nunataks near the Sentinel Mountains, Mt. Johns, and Mt. Ewing consist of folded, unfossiliferous quartzite and low grade schist. The structural trend is slightly east of north and may be extended to intersect the Horlick Mountains or extended to join the Edsel Ford Ranges.

Mt. Takahe is an andesitic, volcanic peak. The area between this peak and the Executive Committee Range may consist of similar volcanic rocks and thus represent a segment of the circum-Pacific volcanic belt.

The Windmill Islands consist of Precambrian gneiss and granitic rocks. The intrusion and metamorphism took place about 1000 my ago. Charnockites are rare, and only one sedimentary rock has been found in the moraines.

36. — *Prof. Lomnitz* reads the paper by *L. Ponce :* Preliminary gravity results on the Deception Island.

A preliminary gravity survey was made on the South Shetlands Archipelago during the 1959-1960 Antarctic summer. Detailed profiles on Deception Island revealed some large gradients indicating unusual structural complexity of this interesting volcanic island. The survey will be completed during the coming summer field season.

37. — *J. N. Nanda :* Evaluation of average crustal characteristics from reverberation of seismic waves. This paper was given by *Dr. Nanda* towards the end of the 5th Session, but is included here.

The seismic records obtained near the shot points during the study of the Earth's crust by the Department of Terrestrial Magnetism, Carnegie Institution of Washington, have been analysed to investigate the possible origin of the reverberations of seismic waves. The hypothesis of layers of uniform velocities fails to explain the reverberation curves in different regions. As a first approximation, the average gradient of velocity with depth can be determined and it agrees with the travel-time data provided one assumes the major contribution to be from the conversion of P waves into S waves at the surface irregularities. The average gradient in Virginia, U.S.A., is seen to be 0.075 km/sec per km.

When the travel-time curves are investigated on the basis of such a large velocity gradient, the penetration corresponding to rays causing intense arrivals usually associated with the critical reflections from the Mohorovičić discontinuity comes out to be only 14 km in Virginia, USA. The intense arrivals have to be ascribed now to the focussing effect of peculiar variation in the velocity at about this depth. For example, if sediments extend to a thickness just short of 14 km, the velocity might increase at the base of the sediments to a value greater than the velocity in the upper layers of the converted crustal rock during the formation of the continents. This will give rise to both a low-velocity layer and focussing when the velocity again increases at depths somewhat greater than 14 km.

On the basis of the ray theory assuming uniform increase of velocity with the depth, expressions have been derived for the reverberation curves for various kinds of single scattering and the average gradient has been determined for various regions. A mathematical theory for the variation of gradient from a high value at the surface to a negligible value when velocities greater than 8.8 km/sec or so are reached would be a logical next step.

The paper has been published in *Proc. Roy. Soc., London,* A, Vol 256, 1960, pp. 28-38.

The session is closed at 12.30.

12th SESSION

FRIDAY, JULY 29 (afternoon)

Program

1. — Scientific communications : Ocean Floor.

38. — *D. B. Ericson :* Stratigraphie des sédiments de mer profonde et la durée du Pléistocène.

39. — *S. M. Zverev :* Seismic data on the sedimentary structure in some sections of the Pacific Ocean.

40. — *U. Hochstrasser* and *R. Stoneley :* The transmission of Rayleigh waves across an ocean floor with two surface layers.

41. — *J. B. Hersey :* Evidence of sediment ponding in deep oceans.

42. — *J. L. Worzel, M. Talwani,* and *C. L. Drake :* Gravity studies of continental margin structures.

43. — *C. L. Drake* and *M. Landisman :* Geophysical studies of the continental margin of eastern North America.

44. — *W. J. Ludwig, M. Ewing,* and *J. Ewing :* Geophysical investigations in the submerged Argentine coastal plain and Scotia Sea.

45. — *J. Nafe* and *C. L. Drake :* The structure of the outer ridge north of Puerto Rico.

46. — *J. L. Worzel, M. Talwani,* and *M. Landisman :* Gravity anomalies on sea mounts.

47. — *M. Talwani, B. C. Heezen,* and *J. L. Worzel :* Gravity anomalies, physiography and crustal structure of the Mid-Atlantic Ridge.

This symposium is held together with IAPO. It is opened at 14.25 with *Prof. Ewing* as chairman.

1. — Scientific communications : Ocean Floor.

38. — *Mr. Ericson* gives his paper : Stratigraphie des sédiments de mer profonde et la durée du Pléistocène.

Il est vain de chercher de longues chroniques des changements de climat du Pléistocène dans les carottes prélevées dans les bassins profonds où se trouvent des sédiments apportés par des courants de turbidité. D'autre part, il arrive souvent que les carottes prélevées sur des élévations du fond contiennent des lacunes à cause d'éboulements sous-marins. Il est difficile, parfois même impossible de constater la présence de ces lacunes dans une carotte unique. Le seul moyen sûr de distinguer les coupes sédimentaires complètes des autres est de faire une corrélation entre plusieurs carottes prélevées en des stations voisines. Mais on ne doit pas se contenter de faire une corrélation des zones climatiques seulement puisque celles-ci ne sont pas nécessairement isochrones. Il faut en outre faire des corrélations des horizons stratigraphiques déterminées par des changements de sens d'enroulement de certaines espèces de foraminifères planctoniques.

Au moyen de cette méthode de corrélation appliquée aux carottes et mise en œuvre au Lamont Geological Observatory on est en train de déterminer une coupe type des sédiments du Pléistocène de l'Atlantique. Bien que l'interprétation de cette coupe à l'égard de l'histoire climatique du Pléistocène puisse être mise en question, sa continuité peut être regardée comme démontrée.

Une interprétation provisoire des zones climatiques déterminées à l'aide des foraminifères planctoniques dans une longue carotte prélevée dans l'Atlantique équatorial aboutit à la conclusion que le fond de la carotte atteint une zone corrélable avec la glaciation du Mindel. Une extrapolation basée sur le taux de sédimentation déterminé par la méthode du radiocarbone indique que la coupe représente une durée d'environ 550.000 années. En supposant que les durées du Günz et du Donau étaient comparables à celles des âges glaciaires subséquents, on arrive à une durée totale du Pléistocène qui n'est guère moindre qu'un million d'années.

39. — *Mrs. Dr. Kosminskaya* presents the paper by *S. M. Zverev :* Seismic data on the sedimentary structure in some sections of the Pacific Ocean.

Investigations of the crustal structure, carried out in 1958-1959 according to the IGY program in the zone of transition from the Asiatic continent to the Pacific Ocean, gave numerous data on the sedimentary structure.

For this purpose use was made of once — and multiply — reflected water waves recorded on long distances as well as of simultaneously recorded seismic waves arriving from deep boundaries in the crust, and also of vertical reflections recorded by multichannel sets on fixed stations and by unichannel sets on moving ships.

Data on velocities in the sediments were obtained from an analysis of the multi-reflected water waves and of the reflection coefficients corresponding to vertical incidence.

Due to the small intervals between the observation points detailed information was collected on the boundaries in the sediments and several high amplitude faults were discovered crossing all the sedimentary layers.

It was found that the Kurile-Kamchatka and the Aleutian deep-water depressions differed essentially in sedimentary structure of the ocean bed.

The paper will be published as follows :

1) In Russian in *Izv. Acad. Sci. USSR, Ser. Geolog.*, 1961.

2) In English in *Annali di Geofisica.*

40. — *Dr. Stoneley* gives the paper by *U. Hochstrasser* and *R. Stoneley :* The transmission of Rayleigh waves across an ocean floor with two surface layers.

This is the second part of an investigation which seeks to obtain values of the wave velocity and group velocity of waves of Rayleigh type following ocean paths corresponding to the structures indicated by experimental investigations using explosions at sea. Eight different models were considered, with ocean depths 4 or 6 km., a sedimentary layer of depth 1 or 2 km., underlain by basic rocks of thickness 5 or 7 km.; in all cases these structures were supposed to rest on ultrabasic rocks of great thickness.

The wave velocity was found for a series of values of the wave-number by solving the eleven-row determinant found in the first part ; the computations were performed by the use of the SEAC electronic computer of the U.S. National Bureau of Standards, and from these values the corresponding values of the group velocity were obtained by numerical differentiation. The general agreement of these dispersion curves with observed values indicates that they should be useful in determining the ray track and time of passage of a train of Rayleigh waves crossing an ocean floor whose structure and depth are varying from place to place.

This paper will be published in the *Geophysical Journal,* Vol. 4, 1961 ("Special Harold Jeffreys Volume"). Part I : Theoretical, by R. Stoneley, was published in *Bull. Seism. Soc. Amer.,* Vol. 47, No. 1, 1957, pp. 7-12.

Dr. J. Darbyshire : Would it be possible to extrapolate the results obtained for 4 km and 6 km depth to depths of 1 km ?

Dr. Stoneley : Calculations show that the wave velocity tends to a constant value at depths below 100 meters and to another constant value for depths greater than 1000 meters with sharp variation between the two for 6 sec waves.

Somebody in the audience says that additional computation is required for short periods, and that higher modes should be included in a new computation.

41. — *Dr. Hersey* gives his paper : Evidence of sediment ponding in deep oceans.

High precision, high resolution echo soundings taken in deep oceans and seas over the past three years suggest that many enclosed topographic depressions have remarkably flat floors. These floors are a few hundred meters to many miles across and are underlain by equally flat-lying strata as revealed by secondary echoes. A few of these have been studied in detail both with an echo-sounder and by coring. The topography and bedding suggests that the sediments have moved downslope to be ponded in the depressions. Sound velocity measurements in the cores have been compared with various properties of the core material and with the echo sequence recorded at the core location. These results will be discussed in relation to the probable history of the sediment ponds.

The paper is submitted for publication in *Deep-Sea Research.*

42. — *Prof. Worzel* reads the paper by *J. L. Worzel, M. Talwani,* and *C. L. Drake :* Gravity studies of continental margin structures.

Many gravity profiles across the continental margin of the East and West coasts of the United States have been made. In most cases much seismic data has provided information of the structure of the upper part of the crust. Using these data as a control the deeper structure section is inferred based on the gravity data.

Comparisons are made for the East and West coasts. The variations along the East coast are discussed in some detail. The true continental edge is the thousand fathom curve. Continental crustal thicknesses thin in about two hundred kilometers to oceanic crustal thicknesses.

The material presented is published as follows :

1) J. L. Worzel and G. L. Shurbet : Gravity anomalies at continental margins, *Proc. Nat. Acad. Sciences,* Vol. 41, 1955, pp. 458-469.

2) J. L. Worzel and J. C. Harrison : Gravity at sea, *The Seas : Ideas and Observations,* Interscience Publishers, Inc., Chapter 5.13 (in press).

Dr. Harrison : Examination of a continuous surface ship gravity profile across the continental slope off southern California has shown that the gradient of Bouguer anomaly is steeper than can be accounted for by a vertical Moho interface. This can only mean that the density assumption in making the Bouguer reduction was incorrect, but it is clear that the Moho interface must be very steep. The topographic transition is also very sudden along this section.

Prof. Worzel, in reply to a question by *Prof. Vening Meinesz*, says that a Moho discontinuity has been found everywhere they have data.

43. — *Dr. Landisman* presents the paper by *C. L. Drake* and *M. Landisman :* Geophysical studies of the continental margin of eastern North America.

The structure of the continental margin of northeastern America has been determined in some detail by geophysical and geological investigations. Seismic and magnetic investigations have revealed the configuration of the upper layers while gravity measurements have determined the depth to the mantle.

Some of the finer details of the structure and the properties of the upper layers have been studied using these techniques and others, including large and small scale seismic reflection methods and analysis of dispersion of sound in the sedimentary section.

These studies have revealed the presence of a buried sea mount with some 4000 feet of relief under the continental shelf of New Jersey, have demonstrated the degree of roughness of the basement surface, and have contributed to our knowledge of the physical properties and the nature of the sedimentary column.

Many results of the investigations of the ocean floors have been compiled in the recent book by B. C. Heezen, M. Tharp, and M. Ewing : The Floors of the Oceans, I. The North Atlantic, *Geol. Soc. Amer., Spec. Paper 65,* 1959, 122 pp. and numerous figures and plates.

44. — *Dr. Ludwig* reads the paper by *W. J. Ludwig, M. Ewing,* and *J. Ewing :* Geophysical investigations in the submerged Argentine coastal plain and Scotia Sea.

During the winters of 1956, 1957 and 1958 extensive seismic refraction studies were conducted on the Argentine continental shelf and adjacent deeps. The expeditions were jointly supported and conducted by the Lamont Observatory and the Hydrographic Service of the Argentine Navy. This report is primarily concerned with the results of the measurements in the Buenos Aires province and the Scotia arc. Preliminary results from the continental shelf south of the Buenos Aires province to Tierra del Fuego are discussed briefly.

Two elongated asymmetrical sediment-filled depressions in the Pre-Cambrian basement complex of the continental shelf in the Buenos Aires province area were traced seaward. The basins are approximately perpendicular to the present shoreline. On land they are separated by the Tandil high which reaches its maximum elevation in a succession of fault-block hills oriented parallel to the basins. The Tandil high is observed to extend seaward under the continental shelf separating the basins. It is delimited by the seismic-refraction profiles and exhibits a marked magnetic anomaly.

Several seismic sections and a basement contour map showing the important structural features in the Buenos Aires province are presented.

The Scotia arc exhibits a sequence of major seismic horizons similar to that found on the adjacent portion of the continental shelf. The results of measurements across the central portion of the Scotia arc together with measurements across Burdwood bank and the Falkland island vicinity are shown in seismic sections.

The full paper has not yet been published or submitted for publication, as some new data from Vema's 16th expedition will also be included. For preliminary information, see *IGY Bulletin, Nat. Acad. Sci.*, No. 33, 1960, pp. 4-6.

45. — *Prof. Nafe* gives the paper by *J. Nafe* and *C. L. Drake* : The structure of the outer ridge north of Puerto Rico.

An intensive investigation was made of the outer ridge north of Puerto Rico during June 1959, to determine its feasibility as a site for a possible borehole through the crust of the earth to the mantle. Participating in this work were personnel and research vessels from Lamont Observatory and Hudson Laboratories, Columbia University; the Woods Hole Oceanographic Institution; and the Department of Oceanography, Texas A. and M. College.

Included in the investigations were seismic refraction measurements using the four vessels, seismic reflection measurements, magnetic and gravity observations, the collection of sediment cores coupled with measurements of the temperature gradient in the sediments, photography of the ocean floor, biological collections of bottom dwelling and planctonic fauna, and studies of the water column and the currents by means of hydrographic and geomagnetic electrokinetograph measurements.

The results indicate that the depth to the mantle in this area is somewhat less than in most parts of the Atlantic Ocean. With the exception of a slight positive gravity anomaly, the outer ridge exhibits no anomalous behaviour of its observed properties.

46. — *Prof. Worzel* gives the paper by *J. L. Worzel, M. Talwani,* and *M. Landisman* : Gravity anomalies on sea mounts.

Gravity anomalies have been observed over a number of sea mounts of various sizes. Over three of these continuous gravity measurements with the Graf Sea Gravimeter have given much more detailed knowledge than exists for the others with only pendulum observations. With the detailed surveys as a guide it is possible to make a reasonable analysis of the data around other sea mounts where detailed data is lacking.

Using the three-dimensional computation technique programmed for IBM computers, recently published by Talwani and Ewing, curves of gravity anomalies have been computed for these sea mounts and compared with the observed anomalies for the ranges of density contrast likely to occur in such sea mounts. Seismic control exists for one of the sea mounts making the density range more restricted for this case.

It is concluded that there is little or no isostatic anomaly for the smaller sea mounts, grading to almost perfect compensation at the base of the crust for the larger sea mounts.

Part of the material presented will be published by J. L. Worzel and J. C. Harrison : Gravity at sea, *The Seas : Ideas and Observations,* Interscience Publishers, Inc., Chapter 5.13 (in press).

47. — *Dr. Talwani* reads the paper by *M. Talwani, B. C. Heezen,* and *J. L. Worzel :* Gravity anomalies, physiography and crustal structure of the Mid-Atlantic Ridge.

A relationship between gross physiography of the Mid-Atlantic Ridge and gravity anomalies has been noted earlier. However, until the advent of the continuous recording sea gravimeter, the wide spacings of the individual gravity measurements precluded a detailed investigation of this relationship. In 1958, a Graf Sea Gravimeter was used aboard the U.S.S. Compass Island to obtain continuous gravity measurements across the Mid-Atlantic Ridge. In deducing the crustal structure from these measurements, the available seismic refraction data were utilized. Consideration was also given to the discrete gravity values made in submarines by Vening Meinesz and by the Lamont Observatory.

The entire Mid-Atlantic Ridge is characterized by positive free-air anomalies. Anomalies corrected for water depth are systematically smaller over the ridge than over the ocean basins. Minimum values are found over the crest provinces.

A median rift valley associated with the mid-Atlantic seismic belt was found in earlier work to show a large positive magnetic anomaly. The free-air anomalies on the Compass Island gravity profile show a 50 mgal minimum over the Rift Valley. A two-dimensional computation to correct for the water depth essentially eliminates this minimum. A three-dimensional correction cannot be expected to change this result appreciably. This is surprising since the other geophysical methods show such distinctive anomalies.

Part of the material presented will be published in the reference under paper no. 46. The full paper will appear in *Publications du Bureau Central Séismologique International, Sér. A, Trav. Sci., Fasc. 22.*

The session is closed at 17.15.

13th SESSION

FRIDAY, JULY 29 (afternoon)

Program

1. — Scientific communications : Constitution of the Continental Crust ; cont.

48. — *J. Oliver, G. Sutton,* and *M. Ewing :* Some results of the IGY long-period seismology program — continental crust.

49. — *N. Öcal :* Die Dispersion der seismischen Oberflächenwellen im asiatischen Kontinent.

50\. — *I. N. Godin :* The study of structure of the crust under regional seismic investigations in Russian platform and in Middle Asia.

51\. — *D. I. Sikharulidze :* Dispersion of Love waves and study of Earth's crustal structure from observational data of the Tbilisi seismic station.

52\. — *J. S. Steinhart, R. P. Meyer,* and *G. P. Woollard :* Seismic measurements of crustal structure in three areas of North America.

53\. — *Commission Séismologique Européenne :* Rapport de la sous-commission des explosions alpines ; expériences de 1956 et de 1958.

54\. — *R. P. Meyer, J. S. Steinhart, G. P. Woollard,* and *M. F. Bonini :* Crustal structure in the Rocky Mountains (Part II : Observations along structural strike).

The session is opened at 14.35 with *Sir Harold Jeffreys* as chairman.

1. — Scientific communications : Constitution of the Continental Crust (cont.).

48\. — *Dr. Oliver* presents the paper by *J. Oliver, G. Sutton,* and *M. Ewing :* Some results of the IGY long-period seismology program — continental crust.

Stations of the International Geophysical Year long-period seismology program recorded seismic waves from a large number of earthquakes for which the paths to the station were entirely continental. In such cases the major features of the directly arriving surface waves may be explained as the result of normal mode propagation within the earth's crust-mantle system. Love and Rayleigh waves of the fundamental as well as one or two higher modes are commonly observed. A general similarity between the various seismograms for shocks with completely continental paths is observed for all continents except Antarctica, where no observations are available. There are small differences in observed dispersion for different paths, however, which may be interpreted in terms of crustal structure and these results are generally in agreement with those obtained from refraction shooting.

The paper is in preparation for publication.

The chairmanship is handed over to *Dr. Oliver.*

49\. — *Dr. Sponheuer* reads a summary of the paper by *N. Öcal :* Die Dispersion der seismischen Oberflächenwellen im asiatischen Kontinent.

En utilisant les séismogrammes de l'Observatoire de Kandilli concernant les années 1936-1951 nous avons étudié la dispersion des ondes de Love et de Rayleigh des séismes dont l'épicentre tombe sur la côte est de l'Asie.

Pour la construction des courbes théoriques de dispersion des ondes de Love nous avons profité des nomogrammes de Y. Sato.

Les valeurs des paramètres obtenues sont : pour les ondes de Love: $H = 30$ km, $\beta = 3{,}40$ km/sec, $\beta/\beta' = 0{,}85 - 0{,}95$, $\mu/\mu' = 1{,}5$; et, pour les ondes de Rayleigh : $H = 27$ km, $\beta = 3{,}40$ km/sec, $\beta/\beta' = 0{,}76$, $\mu/\mu' = 1{,}65$.

Acceptant assez bien l'adaptation des empiriques, tracés pour les ondes de Rayleigh, Aléoutiennes et Kamchatka (I), Kouriles, Hokkaido et Honshu (II), Formose, Philippines et Célèbes Nord (III), les paramètres théoriques ci-dessus sont déterminés pour une courbe moyenne de dispersion identique à celles-ci. De la comparaison de la courbe (III) avec celles des Nos (I) et (II), on a conclu que la structure géologique de l'Asie du Sud est différente de celles de l'Asie du Nord et Centrale.

The full paper has been published in *Gerlands Beiträge zur Geophysik,* Bd 69, H. 1, 1960, pp. 35-56.

50. — *Prof. Riznichenko* reads the paper by *I. N. Godin :* The study of structure of the crust under regional seismic investigations in Russian platform and in Middle Asia.

Since 1948 the regional seismic works have been widely applied in the total complex of geophysical investigations for the most complete studying of the regional geological structure of the vast closed territories. These works are carried out along the traces of the extensive bearing profiles and the systems of separate soundings.

To solve a number of geotectonic problems and some questions appearing in the interpretation of the gravity and magnetic anomalies the investigations are carried out in order to find out the abyssal structure of the crust. These works have been conducted since 1956 along the traces of the separate bearing profiles with a simultaneous study of the structure of thick sedimentary series and the surface of foundation.

During three years the abyssal structure of the crust had been studied along the traces of the bearing profiles for a total distance of about 3000 km, including 1900 km on the Russian platform, 430 km in the Fergana intermountainous depression, 300 km in Turkmenia, 300 km in the Bukhara region.

The methods of studying the abyssal structure of the crust consisted in application of longitudinal continuous profiling along the traces of the bearing profiles with the correlated system of the counter overtaking hodograph of the refracted waves with the simultaneous registration of the deep reflections.

The distance between the explosion points were 40-80 km, between the seismograph groups — 100 m, maximum of the hodograph length is 200-400 km. At the same time the surface of foundation and separate reflecting and refracting horizons in the thick sedimentary series were observed by the special observation system along the traces of the same profiles.

As a result of such detailed investigations there was found out the character of the wave picture in the individual regions and determined the types of the observed depth waves.

In particular the overcritic reflections from the Moho boundary were marked out and observed for large distances.

The peculiarities of the structure of the crust in the principally different geotectonic provinces were cleared up. The total increase of the speed with the depth is observed for the different regions.

In all regions the average speeds to the Moho boundary amount up to 6.2—6.4 km/sec to within 3—4 %. With the most stability the following abyssal seismic limits of partition were marked : the surface of foundation, the limit 5—10 km below the surface of foundation, the basalt surface, the limit below the basalt surface (the basalt limits were marked out unstably in Bukhara), the Moho boundary. The limits placed below the Moho boundary were marked out.

The depth of the Moho boundary changes from 40 km on the Pre-Cambrian Russian platform and the epigercin Kara-Kum one to 45 km on the edge of the south-western Tjan-Shan virgations Zeravshan (Bukhara region) and to 55 km in the Fergana inter-mountainous depression.

There were no marked sharp changes in the relief of the abyssal limits of break and changes in the thickness between the separate horizons along the profiles (with the accuracy of charting 5—6 %). There were not observed as well any sharp sinkings of the abyssal horizons to the Pri-Urals or when crossing the western spurs of Zeravshan. Along the profiles a number of contacts and tectonic breaks were registered by specific peculiarities of seismic records on the surface of foundation. There were outlined some zones where breaks are expected to extend to a considerable part of the crust including the Moho boundary.

The complete paper with the authors I. N. Godin, B. S. Volvovsky, I. S. Volvovsky, and K. E. Fomenko will be published in *Publications du Bureau Central Séismologique International, Sér. A, Trav. Sci., Fasc. No. 22.*

Prof. Pekeris : Do you confirm the observation of Tatel and Tuve that the wave reflected from the Moho discontinuity is best observed at a distance greater than the critical distance for total reflection, i. e. beyond 80 km ?

Prof. Riznichenko : Yes, the waves reflected from Moho are stronger, as a rule, after the critical point, if they are observed. But occasionally they are not observed even in this region — the region of the refracted wave. For distances short of the critical distance reflections at Moho have been found only in a limited number of cases. For their fair correlation special favourable natural conditions and methodical measures are important.

Prof. Rothé : N'est-il pas étonnant que les ondes Po (Pg) s'inscrivent si faiblement sur les séismogrammes alors que au contraire les Pn ont une très forte amplitude ?

Prof. Riznichenko : This is a well established fact, which could be explained by inhomogeneities in the granitic layer. In this case the wave attenuation in this layer may be significant and reduce the Pg amplitude at greater distances. As to the large amplitude of Pn, it may be caused by : 1) a small attenuation of waves in the rock material immediately beneath the Moho ; 2) the influence of the penetrating effect, if the velocity in this depth portion raises.

Prof. Press : Is the intermediate layer velocity of about 7½ km/sec common in the USSR highlands ? Is there a correlation of the occurrence of this velocity with topography or structure ?

Prof. Riznichenko : Such a high velocity has been well defined by the detailed observations by Godin in Kara-Kumi, Fergana, Volga-Ural district. These are not mountain regions, and the topography is of no significance. — The two-layered structure with a basaltic layer has been found in the Pamir region (I. P. Kosminskaya, G. G. Michota, and J. V. Tulina : *Izv. Acad. Sci. USSR, Ser. Geofiz.*, 10, 1958, pp. 1162-1180, and in German in *Bergakademie*, 11, 1959, pp. 669-672) and in more detailed studies of industry (Godin, published in Russian in *Sovjetskaya Geologia* and *Geologia Nefti*).

51. — *Mrs. Dr. Vvedenskaya* reads the paper by *D. I. Sikharulidze :* Dispersion of Love waves and study of Earth's crustal structure from observational data of the Tbilisi seismic station.

1. For the study of the Earth's crustal structure on the basis of experimental data on the dispersion of Love waves, the records of African, Chinese, Japanese, Himalayan, Philippine earthquakes, written at the Tbilisi teleseismic station of the Institute of Geophysics of the Academy of Sciences of the Georgian SSR have been drawn upon. Experimental dispersion curves of Love waves available for these earthquakes differ considerably from each other. Grouped according to the dispersion properties, these earthquakes show the following three-fold alignment :

a) The Caucasus — Central Asia — China — Japan

b) The Caucasus — the Himalayas — the Philippines

c) The Caucasus — Africa.

2. The best conformity between the experimental and the theoretical dispersion curves of Love waves in the alignment Caucasus — Central Asia — China — Japan is for the two-layered crustal model, with the thickness of the granitic layer $H_1 = 20$ km and of the basaltic layer $H_2 = 20$ km, and with the following ratios of velocities and densities :

$$v_1/v_3 = 0.7 \; ; \; v_2/v_3 = 0.8 \; ; \; v_3 = 3.7 \text{ km/sec.} \; ;$$
$$\rho_1/\rho_3 = 9/19 \; ; \quad \rho_2/\rho_3 = 10/10.$$

The conformity between the experimental and the theoretical curves is satisfactory also for the one-layer crustal model with the total thickness $H = 40$ km.

3. In the alignment Caucasus - Himalaya - Philippines the values of Love-wave group velocities for the earthquakes of the Philippine Islands are somewhat greater than for the other earthquakes on the same route. The best conformity of the experimental curves with the theoretical curves for the Philippine earthquakes is for the two-layered crust with $H_1 = 25$ km, $H_2 = 20$ km, $v_1 = 3.3$ km/sec, $v_2 = 3.7$ km/sec, $v_3 = 4.5$ km/sec, $\rho_1 = 2.7$ g/cm³, $\rho_2 = 2.9$ g/cm³, $\rho_3 = 3.3$ g/cm³.

For other earthquakes of this route the experimental dispersion curves show better conformity with the theoretical curves for the two-layered model with the total thickness $H = 50$ km and with $H_1 = 25$ km, $v_1/v_3 = 7/10$, $v_2/v_3 = 4/5$, $v_3 = 4.7$ km/sec, $\rho_1/\rho_3 = 9/10$, and $\rho_2/\rho_3 = 10/11$.

The decrease in crustal thickness determined on the basis of Philippine earthquakes is to be accounted for by the fact that a considerable part of the route of Love waves lies under sea depressions.

4. Along the lines Caucasus - Africa the values of Love-wave group velocities for earthquakes of Africa are found to be greater than those for the earthquakes that have just been considered. The best conformity between the experimental and the theoretical curves along the line is obtained for a two-layered crustal model with $H_1 = 15$ km, $H_2 = 15$ km, $v_1/v_3 = 0.7$, $v_2/v_3 = 0.8$, $v_3 = 4.7$ km/sec, $\rho_1/\rho_3 = 0.9$, $\rho_2/\rho_3 = 10/11$.

The complete paper has been published in Russian in *Trud. Inst. Geofiz., Acad. Sci. Georgian SSR*, Vol. 17, 1959.

52. — *Dr. Meyer* presents the paper by *J. S. Steinhart, R. P. Meyer,* and *G. P. Woollard* : Seismic measurements of crustal structure in three areas of North America.

Crustal structure has been determined from blast observations in Central Mexico, Wisconsin, and Arkansas, representing respectively, a plateau area, a pre-Cambrian shield area and a "positive" cratonic element. The combined use of travel-times of reflections and refractions, amplitudes and gravity anomalies allow rather narrow restrictions to be placed on the structure deduced. Results are given and the implications of geologic history discussed.

The full paper is expected to be published in the *Journal of Geophysical Research.* See also a paper by G. P. Woollard in the *Journal of Geophysical Research,* Vol. 64, No. 10, 1959, pp. 1521-1544.

Prof. Press : Use of reflection amplitude versus distance to distinguish between possible solutions is dangerous when theoretical curves are based on homogeneous layers and razor-sharp interfaces. Slight velocity gradients can greatly change the amplitude curves. Also, normalizing the reflection amplitude by comparison with Pg assumes monotonic behavior of Pg amplitude. Is this safe in view of possible local effects ?

Dr. Meyer : We feel that the position (range) at which the critical reflection occurs may shift due to gradational boundaries such that it may not be possible to distinguish cases which are very similar.

Many possible refraction models are very different from one another and these I feel can be safely evaluated. Local effects are assumed to have largely the same effects on the refracted and reflected amplitudes at any particular recording station.

Prof. Riznichenko : 1) Has the correlation principle been used to distinguish waves of different types ? For such a purpose a many-channel field station is important. 2) What was the distance between adjacent seismic receivers ? 3) What is the distance between the dots as shown on the time-distance graphs ?

Dr. Meyer, in reply : 1) The "correlation principle" which is really an extension of normal commercial refraction technique, is currently used whenever topographic and logistic conditions permit. It is being applied with increasing frequency. 2) Currently seismometers are spaced at ½ km. 3) The distance between the points dotted is variable. In early work it may be as far as 10 km. In recent work the points are spaced as close as 2.5 km. Each point represents the center of a spread of about 2 km length.

Mr. Figueroa says that the explosions in Durango (1957 - autumn) were recorded in Tacubaya and wants exact times for the explosions.

53. — *Commission Séismologique Européenne :* Rapport de la sous-commission des explosions alpines ; expériences de 1956 et de 1958.

Prof. Closs demonstrates the results of the Alpine explosions in 1956 and in 1958 by means of a three-dimensional model.

Mme Labrouste completes the presentation.

54. — *Dr. Meyer* presents the paper by *R. P. Meyer, J. S. Steinhart, G. P. Woollard,* and *M. F. Bonini :* Crustal structure in the Rocky Mountains (Part II : Observations along structural strike).

Two reverse seismic refraction profiles were shot in the Rocky Mountain province, one located in Western Montana near and parallel to the Continental Divide and one north-south profile in Eastern Montana on the east flank of the Rocky Mountains. The length of these profiles was approximately 350 kilometers. In the profile from south to north in Eastern Montana continuous phase correlation techniques were applied in the range 100-250 kilometers from the shot point.

Principal phases were present on nearly all records as primary or secondary events. Other secondary events correlated over rather wide areas appear not to be directly related to simple reflection or refraction events. In both cases least square treatment of the data yields compatible results for the two ends of the profiles. Preliminary results indicate that the overall thickness of the crust is about 48 kilometers in both areas. Some thickening of the intermediate layer in the Central Rockies is indicated. The observed velocities in the upper layer are somewhat lower in the Central Rocky Mountains. Average crustal sections are as follows :

Eastern Profile — 1.76 km of 2.75 km/sec material ; 1.6 km of 4.6 km/sec material ; 23.6 km of 6.15 km/sec material ; and 21.4 km of 7.4 km/sec material. The upper mantle velocity is 8.11 km/sec.

Western Profile — 2 km of 4.3 km/sec material ; 17 km of 5.95 km/sec material ; 30 km of 7.4 km/sec material. The upper mantle velocity was 7.93 km/sec. Interpretation of these results in the light of gravity anomalies, major geological structure and isostasy is discussed.

The paper is expected to be published in the *Journal of Geophysical Research.*

The session is closed at 17.15.

14th SESSION

SATURDAY, JULY 30 (morning)

Program

1. — Scientific communications : Seismological Geography.

55. — *M. Båth :* Methods of measuring and mapping seismicity.

56. — *V. Kárník :* Seismic maps of Europe.

57. — *J. P. Rothé :* Les enseignements du séisme d'Agadir (29 février 1960).

58. — *L. Glangeaud :* Exposé de la séismicité de la région méditerranéenne.

59. — *N. Öcal :* Die Seismizität und Erdbebengeographie der Türkei.

60. — *A. Grandjean :* Les séismes du Hoggar.

61. — *S. L. Soloviev :* Some aspects of seismicity of the U.S.S.R.

62. — *A. D. Tskhakaya :* Studies of Caucasian earthquakes ; basic results.

63. — *Y. V. Riznichenko* and *I. L. Nersessov :* Étude détaillée du régime séismique dans la région épicentrale de Garm.

64. — *V. N. Gaisky :* On the study of Tadjikistan seismicity from observations of central Asiatic regional seismic network.

65. — *I. E. Gubin :* Development of geological structure and seismicity of the southern part of Middle Asia.

66. — *V. I. Bune :* Some results of detailed study of the Stalinabad district seismic regime in 1955-1958.

67. — *S. Miyamura :* Earthquake province and its bearing on geotectonics.

The session is opened at 9.05 with *Prof. Richter* as chairman.

1. — Scientific communications : Seismological Geography.

55. — *Dr. Båth* gives his paper : Methods of measuring and mapping seismicity.

It is desirable to express the seismicity in quantitative measures. This is evident if we want to compare different seismic areas as well as in comparisons of different time intervals for a given area. It is also necessary in mapping the seismicity. But it is equally desirable that seismicity is defined in quantities of clear physical significance and not as an arbitrary function of macro- or microseismic quantities.

Provided that only shocks above a given lower magnitude limit, the same for the whole area considered, are taken into account it is demonstrated that the following quantities are interrelated : number of shocks, energy, strain release, maximum magnitude, maximum intensity. Therefore, isolines for all these and related quantities will be identical, and any of these quantities can be used to represent the seismicity.

This paper constitutes the last chapter in a more extensive paper by M. Båth : Seismicity of Europe — A Progress Report, *IUGG Monograph,* No. 1, 1960, 24 pp.

Prof. Tsuboi : 1) In formula log $N = f - g M$, the quantities f and g are related to each other. 2) Strain proportional to $E^{\frac{1}{2}}$ assumes a constant strain volume.

Dr. Båth, in reply : 1) I agree, but this does not change my argument. 2) My use of the relation — strain proportional to $E^{\frac{1}{2}}$ — is equally justified as in Benioff's papers.

56.— Mr. Kárník presents his paper : Seismic maps of Europe.

In agreement with the resolutions of the European Seismological Commission the work on the project "Seismicity of Europe" continued in 1959-1960 with the compilation of first drafts of earthquake catalogue and of epicenter maps for shocks with $I_0 \geqslant$ VI, which occurred in the interval 1901-1955.

The catalogue contains all information sent by almost all member countries of the E.S.C. The collected data, but without revision, are given in the catalogue in the following order : Year, month, date, origin time (GMT), epicentral coordinates, depth of focus, magnitude, maximum intensity, radius of perceptibility, references, additional remarks. The total number of earthquakes included in the catalogue reaches 3608 (incl. 145 deep-focus earthquakes).

All the data available were used for the preparation of first drafts of epicenter maps in the scale 1 : 5 000 000. For the symbols, denoting the foci, circles (shallow earthquakes) and triangles (intermediate and deep-focus earthquakes, $h \geqslant 60$ km) were taken. Different quality of information is marked by small changes of the symbols, e. g. the uncertainty in intensity is denoted by dashing the contour line, etc. The great number of foci enforced the division of data in four maps : Shallow earthquakes with $I_0 =$ VI, with $I_0 =$ VII, with $I_0 =$ VIII, with $I_0 =$ IX-XII and deep-focus earthquakes. The maps give the first information about the position of seismic zones in Europe. However, it must be emphasized, that the catalogue and the maps present the collected information without any revision or correction. They were prepared mainly for discussion on definite methods. The information is not fully homogeneous (foci in the sea) and accurate, therefore the following tasks have to be solved before the final catalogue and seismic maps can be presented :

1. Uniform classification of earthquakes using the quantity M (provided know relation between M, I_0, h and r valid for Europe).
2. Final maps of epicenters for the intervals 1901-1955 ($I_0 \geqslant$ VI), 1801-1900 ($I_0 \geqslant$ VII), before 1800 ($I_0 \geqslant$ IX) and for shallow and deep-focus earthquakes.
3. Map of seismic zoning with maximum isoseismals differentiated according to the number of observations.
4. Seismicity map (using e. g. the quantity d in the formula $\log N = cM + d$).
5. Regional studies.

The copies of my report together with the first epicenter maps will be distributed to all members of the European Seismological Commission and the text will be published in the *IUGG Monograph,* no. 9, 1961, 31 pp., as the continuation of the first report by Dr. M. Båth.

Prof. Shneiderov : The Lorentz' transformation requires that the Earth should contract in the direction of its motion through space by $(1-v^2/c^2)^{1/2}$ multiplied by its diameter at rest, v being the resultant velocity of the Earth motion in space, and c is the speed of light. This compression calls for deformation of the Earth and subsequent stresses and strains in its crust. Such stresses and strains may trigger the earthquakes along the great circle perpendicular to the said vector velocity of the Earth. It is important therefore to study the distribution of simultaneous earthquake epicenters along great circles of the Earth. The questions are whether or not a table of simultaneous earthquakes was worked out in the report of Mr. Kárník, and what period was covered by the tables provided in the catalogue of earthquakes submitted with the paper.

Mr. Kárník : The period covered by the catalogue is 1901-1955.

57. — *Prof. Rothé* reads his paper : Les enseignements du séisme d'Agadir (29 février 1960).

1. Aucun séisme n'était connu dans la région d'Agadir depuis 1731 ; ainsi une étude de prévision du danger séismique doit nécessairement s'appuyer sur des renseignements historiques aussi nombreux que possible.

2. Quoique de magnitude relativement faible (5 3/4) ce séisme a détruit une grande partie de la ville et fait 20.000 morts ; le foyer se trouvait au voisinage immédiat de la ville et à 2 km seulement de profondeur.

3. Les dégâts ont été accentués par de nombreux vices de construction: mauvaise maçonnerie, remplissages ne faisant pas corps avec les ossatures, murs et piliers trop faibles pour supporter une accélération verticale importante.

4. La zone des plus forts dégâts coïncide avec la *flexure preatlasique,* retombée presque verticale de l'anticlinal le plus méridional

du Haut-Atlas. Cet accident tectonique forme le contact entre les chaînes plissées « alpines » et le socle africain. Contrairement aux observations classiques les vibrations se sont très rapidement amorties dans les terrains alluvionnaires de la plaine du Souss.

5. Une étude séismotectonique détaillée est susceptible d'aider à la détermination des zones dangereuses. Pour éviter le retour d'une telle catastrophe toute la partie de la ville d'Agadir construite sur la *flexure* devra être transformée en « *zone verte* », la reconstruction de la ville devant s'effectuer plus au sud dans une zone plus éloignée de l'accident tectonique.

58. — *Prof. Glangeaud* gives his paper : Exposé de la séismicité de la région méditerranéenne.

No abstract or reference has been given for this paper.

59. — *Dr. Sponheuer* reads a summary of the paper by *N. Öcal :* Die Seismizität und Erdbebengeographie der Türkei.

Pour les séismes, au nombre de 1.804 apparus dans l'intervalle de 1850 à 1960 en Turquie nous avons déterminé la magnitude ainsi que l'énergie dégagée à l'aide de formules connues de B. Gutenberg et C. F. Richter ; pour la construction des « isenérgettes » nous avons profité, suivant les définitions et propositions de M. Toperczer et E. Trapp, des valeurs $\delta = \log_{10} S$ de sorte que la quantité d'énergie $S = \frac{\Sigma e_i}{FP}$ appliquée aux surfaces élémentaires 0°,5 Lat. $\times$ 0°,5 Long. soit erg/m² h.

D'autre part, en traçant les cartes de distribution géographique des épicentres, des profondeurs hypocentrales et de fréquence de l'intensité, nous avons recherché la corrélation de la séismicité avec la tectonique du pays.

The paper will appear in the *Publications from the Institute of Seismology of the Technical University, Istanbul.*

60. — *Mlle Dr. Grandjean* reads her paper : Les séismes du Hoggar.

De faibles tremblements de terre ont été ressentis au Hoggar en 1957 et 1958, alors que personne n'en avait jamais signalé. Dix années d'enregistrements effectués à Tamanrasset au moyen d'enregistreurs électromagnétiques à grande amplification ont montré que la séismicité de la région est effectivement très faible (moins de cinq séismes par an en moyenne). La distance épicentrale 80 à 85 km semble prépondérante, c'est celle des secousses ressenties en 1957 et 1958, dont on a pu situer les épicentres à l'WSW de Tamanrasset, vers Silet, dans une région classée par P. Bordet comme de volcanisme récent, qui peut être appelée à une reprise d'activité.

A more extensive text, 4 pp., was distributed in duplicated form during the Assembly.

61.— Dr. Soloviev gives his paper : Some aspects of seismicity of the U.S.S.R.

Main seismic zones of the USSR can be divided into 3 groups.

a) Kamchatka and Kurile Islands are parts of the great circum-Pacific seismic belt and belong to regions of, perhaps, the most intensive present change of the relief of the Earth.

b) The Carpathian Mountains, Crimea, Caucasus, Copet-Dag, Pamirs, Hindu Kush are parts of the Tethys belt, which crosses the whole continent of Europe and Asia ; they belong to regions of Alpide (Mesozoic-Kainozoic) folding.

c) The Tien Shan, Altai, Baikal zones belong to Central Asia region of block mountains arisen during the Kainozoic era.

Other seismic zones of the country (the Arctic, Ural, Khibini and oth.) are less active and their seismotectonic features are not known now sufficiently well.

The earthquakes with the foci under the crust of the Earth happen only at Pacific and Alpide zones and are absent at zones of block structure. Many strong earthquakes at block zones were accompanied with great surface fractures (Kebin earthquake of 1911, Gobi-Altai earthquake of 1957).

Pacific and Alpide zones containing the deep-focus earthquakes can be divided into 2 types :

1) the Carpathian (Vrancea) Mountains and Hindu Kush ;

2) the Kurile-Kamchatka zone and, probably, eastern part of the Caucasus.

In the first zones systems of seismic foci are like a funnel or a cone directed inside the Earth ; main part of the foci is situated under the asthenosphere at the depth of 100-300 km ; the thickness of the crust in the epicentral region amounts to its highest value. In the second zones systems of the foci form inclined plane or conic "layers" which divide the ascending and descending blocks of the crust; main part of the foci is situated above the asthenosphere ; its thickness doesn't surpass the usual value for mountain regions. Many common features with these zones can be found at the Crimea.

The relation between magnitude (M) and frequency (N) of strong ($M \geqslant 5$) earthquakes during 1912-1959 is studied for different zones of the country on the basis of the Atlas of the seismicity of the USSR. For this relation the following form was adopted :

$$\lg N = a - b\,M$$

Preliminary results of the investigation are given in the table, frequency N being the average annual number of earthquakes with $M \pm 1/4$.

Zone	b	$a(b=0.8)$	lg S	a(lg S = 5.5)	M max
Caucasus	0.9-1.2	4.0	5.7	3.8	6.5
Copet-Dag	0.65-0.95	3.4	4.8	4.1	7.0
Middle Asia	0.7-0.8	4.6	5.8	4.3	(7.5)
North Tien Shan	0.6-0.9	3.5	5.2	3.8	(8)
Baikal	0.6-0.8	3.6	5.3	3.8	7.5
Kamchatka and Kurile Is.	0.6-1.0	5.4	6.0	4.9	8.25
Arctic	0.5-0.8	3.8	6.5	2.8	6.5

The accuracy of data doesn't permit to establish if the value of b is the same for different zones or if it is different. The third column of the table indicates the values of a obtained for constant value of b, the fourth column contains approximate values of seismic areas (S) ; the next column values of a reduced to the constant area ; the last one maximal values of magnitude for each zone.

There are simple relations between M max and reduced values of a :

M max $\approx 0.9 + 1.5\ a$ Alpide and Pacific zones;

M max $\approx 2.2 + 1.5\ a$ block zones.

That is, many small earthquakes correspond to a strong earthquake in Pacific and Alpide zones ; few shocks correspond to such earthquake in block zones.

The paper will be published in Russian in *Izv. Acad. Sci. USSR, Ser. Geofiz.*, 1961.

Dr. Båth : I am interested in your graph of distribution of time intervals between earthquakes in the Kurile Islands. At Uppsala we have constructed a similar distribution for the whole Earth, and found, like you, a very close fit to a Poisson distribution. The paper has been published by A. Shlanger (Ben-Menahem) in *Gerlands Beiträge zur Geophysik,* Bd 69, H. 2, 1960, pp. 68-72.

62.— Dr. Gubin reads the paper by *A. D. Tskhakaya* : Studies of Caucasian earthquakes ; basic results.

A systematic study of the seismic phenomena of the Caucasus was begun in the 19th century. The major earthquakes underwent macroseismic investigation, and the results were published. All available information on Caucasian earthquakes prior to 1898 was entered in the Catalogues of Russian earthquakes compiled by I. Mushketov and A. Orlov ; more comprehensive macroseismic information covering earthquakes of more than a millennial period ending with the year 1950 is adduced in E. I. Büss' Chronology. The maps compiled from these data characterize earthquakes as to frequency and intensity and have thus provided a basis for a classification of the Caucasus into regions according to seismic activity.

Instrumental observations at the Tbilisi seismic station began at the end of 1899 ; and from 1902 to 1909 nine seismic stations were set up in the Caucasus. The bulletins of the stations have since then been regularly published in Tbilisi.

The setting up of regional seismic stations in the Caucasus began in 1932 ; and the widening of the regional network was particularly stepped up after 1950. Twentyfour stations, provided with up-to-date supersensitive equipment, are at present functioning in the Caucasus ; their bulletins are published in the summary bulletin of the network of U.S.S.R. seismic stations by the Council on Seismology of the Academy of Sciences of the U.S.S.R.

Seismic elements of Caucasian earthquake epicentres and intensity have been re-determined according to instrumental data for the period 1912-1959. This was done by a group of Caucasian seismologists with a view to incorporating the revised data in the Atlas of Seismic Maps of the U.S.S.R. prepared under the guidance of Prof. E. F. Savarensky.

In the years 1912-1958 430 epicentres were located in the Caucasus zone of $M \geqslant 4$ magnitude ; of this number 28 per cent falls within Turkish or Iranian territory.

It should be noted that $M \geqslant 6$ earthquakes occur chiefly beyond the boundaries of the U.S.S.R. — in Turkey and Iran, which is an indication of the greater seismic activity of those regions ; however, the absence of seismic stations in these territories makes it impossible to fix the epicentres of the smaller earthquakes (sometimes even those of $M = 4$).

The foci of nearly all Caucasian earthquakes are located within the bounds of the Earth's crust. The majority are surface foci with a depth of less than 10 km. Of the five earthquakes that constitute the exceptions, three, with epicentres in the eastern part of the Caucasus, have focal depths of 70-80 km. As to the remaining two, with epicentres in the Caspian Sea, their focal depths are 100 and 150 km. There is generally a tendency towards increased focal depths in the direction of the Caspian Sea.

In the following years (1955-1959), seismologists of the Institute of Geophysics of the Academy of Sciences of the Georgian SSR (it is at this institute that the summary bulletin of the Caucasus zone is being prepared) have compiled maps of earthquakes of magnitudes of $M = 4$ and over, and for the smaller earthquakes — maps of epicentres which give an idea of the density of their distribution over the area.

Epicentres of intermediate and small earthquakes, in the main, fall within areas which are, from macroseismic data, known as regions of earthquakes with intensity numbers VII and VIII. The only exceptions to this are earthquakes of the south-eastern part of the Central and of the Western Caucasus. In this area, an increased seismic activity is being observed since 1955. Through the five-year period 1955-1959, ten earthquakes have occurred with magnitudes $4\ 1/2 \leqslant M \leqslant 5\ 3/4$ causing damage to and destruction of buildings. They follow in their pattern of distribution the zone where the Colchidan Plain contacts the southern spurs of the Main Caucasus Range and of the Ajaro-Trialetian Chain, with a concentration of epicentres in the Gegetchkori-Achigvara region.

Special attention should be given to the cluster of epicentres in the Djavakhetian Plateau — a region of almost continuous small earthquakes with $M \leqslant 2$, and sometimes of up to $M = 6$. The largest of these earthquakes fall in the zone of two deep fault breaks — the Abul-Samsarian and the Djavakhetian, while the frequent small shocks may be accounted for by slippage of separate blocks, in which the crystalline massive underlying the superimposed lava has been broken up.

Another active seismic zone is the region of the Main Caucasus Range adjacent to Mount Barbalo ; here, too, there is a concentration of epicentres to a strip, in a south-easterly direction, along the contact of the southern spurs of the Main Caucasus Range with the Alazani-Agrichai depression. Differentiated Earth's crustal movements are observed here. Seismic activity in the region, particularly in evidence from 1946, still continues, being manifested by frequent earthquakes of magnitude $3 \leqslant M \leqslant 5\ 3/4$.

Epicentres of earthquakes of magnitude $4 \leqslant M \leqslant 6$, too, show a tendency towards centering in the Caspian coastal strip, especially where the northern spurs of the Main Caucasus Range enter the sea.

The complete paper will be published as follows :

1) In Russian in *Izv. Akad. nauk SSSR, Ser. Geofiz.*, 1961.
2) In English in *Publications du Bureau Central Séismologique International, Sér. A, Trav. Sci., Fasc. No. 22.*

Some earlier papers by A. D. Tskhakaya on the same subject have been published as follows :

1) *Trudi Inst. Geofiz., Akad. nauk Georg. SSR*, Vol. 16, 1957, pp. 177-219.
2) *Izv. Akad. nauk SSSR, Ser. Geofiz.*, 1957, No. 6, pp. 785-788.
3) *Izv. Akad. nauk SSSR, Ser. Geofiz.*, 1957, No. 8, pp. 990-999.

63. — *Prof. Riznichenko* presents the paper by *Y. V. Riznichenko* and *I. L. Nersessov :* Étude détaillée du régime séismique dans la région épicentrale de Garm.

1. Le régime séismique est défini en étudiant l'ensemble des séismes de la région donnée, dans l'espace et dans le temps. La distribution de la fréquence de la répétition de la « réitération » des séismes selon leur énergie séismique peut servir comme caractéristique principale quantitative du régime moyen séismique. La réitération rapportée aux séismes d'une certaine classe fixée $K = \log E \pm 0{,}5$ de l'énergie E est la plus simple caractéristique approximative de l'activité séismique AK. En outre, le paramètre $\gamma = \Delta \log N / \Delta \log E$ faisant voir la chute de la réitération des séismes avec l'augmentation de leur énergie et la mesure R des fluctuations de la réitération des séismes dans le temps sont aussi des valeurs très importantes.

2. Dans la région de Garm où la séismicité est élevée on a fait depuis 1955 des études détaillées statistiques du régime séismique ; on a pu ainsi établir les caractéristiques moyennes et les paramètres du régime pour toute la région et ses différentes parties ainsi que les fluctuations des paramètres de ces caractéristiques. La valeur des fluctuations permet d'apprécier l'exactitude de la détermination

des valeurs moyennes et d'établir des cas de déviation du régime observé par rapport à son état moyen à longue durée — c'est-à-dire par rapport à son état « normal ».

3. Une comparaison de la marche horaire des caractéristiques du régime séismique est effectuée pour l'ensemble des séismes d'énergie différente et pour les séismes d'énergie la plus élevée mis à part.

4. Les cartes de l'activité séismique ont été établies et leur exactitude est discutée. De telles cartes donnent une base géophysique pour la division en districts selon la méthode quantitative de l'établissement du degré de danger séismique des régions.

5. Les problèmes essentiels de l'étude ultérieure des régimes séismiques sont les suivants : La précision des régularités moyennes de la réitération dans les régions soumises aux séismes d'énergie très élevée, l'étude des variations possibles à longue durée de la marche de l'activité séismique et l'établissement de l'interaction des particularités des caractéristiques du régime séismique avec des particularités locales géologiques et géophysiques des régions et avec les déformations de l'écorce terrestre étudiées par les méthodes géophysiques, géodésiques et géologiques.

The complete paper will appear in *Annali di Geofisica.*

64. — *Dr. Gaisky* gives his paper : On the study of Tadjikistan seismicity from observations of central Asiatic regional seismic network.

1. The possibility of knowing essence and laws of the seismic development requires combination of the detailed seismic regime field investigations of small sections with systematic piling of the identical observations for a whole region within a long period of time.

2. The existing Central Asiatic network of seismological stations makes it possible to have a clear view of the seismicity in the Republic from the level $E = 1.10^{16}$ ergs for the energy of the elastic waves, radiated from an earthquake focus.

3. The principal epicentral zones of the Republic are connected with borders among the large tectonic structures of Central Asia. The strongest earthquakes of the Republic are associated with these principal zones chosen on the base of observations of relatively weak earthquakes.

4. The study of the dependence between the earthquakes of different intensities enables to draw some conclusions about the character of earthquake distribution in space and time.

Part of the paper has been published in *Trudy instituta seismostoikogo stroitel'stva i seismologii* (Trans. of the Institute of Seismic Engineering and Seismology), *Akad. nauk Tadjikskoi SSR,* Vol. 7, 1960, pp. 27-39. The whole paper will be published in *Izv. Akad. nauk SSSR, Ser. Geofiz.*

65. — *Dr. Gubin* presents his paper : Development of geological structure and seismicity of the southern part of Middle Asia.

1. The southern part of the Middle Asia includes three structures : two mobile belts of the North Pamir — Kuen Lun and the Southern Tian Shan (Hissar-Ali-Turkestan Mountains) and the Intermediate Tadjik-Tarim, which is less mobile structure.

2. During the Paleozoic the mobile belts were geosynclines, the intermediate structure comprised the Tarim stable block and the South Tadjik platform (eastern part of Turan plate).

3. After the Variscian folding, during the Mesozoic the Southern Tian Shan was a platform ; the North Pamir — Kuen Lun territory was going upwards and its northern margin downwards, where the marginal trough originated ; the Tarim stable block existed, the South Tadjik platform was going downwards slowly, unequally.

4. During the Tertiary there began an upheaval (rejuvenation) of the Southern Tian Shan platform; elevation of the North Pamir — Kuen Lun region and the deepening of its marginal trough augmented; the Tarim stable block existed, the South Tadjik platform was unequally, slowly going downwards and upwards.

5. During the Quaternary, the upheaval of the Southern Tian Shan platform and of the North Pamir — Kuen Lun territory extremely increased, and rapid elevation began of the territory of the North Pamir — Kuen Lun marginal trough; little uplifts on the South Tadjik platform originated. Meanwhile in different structures there were folding of corresponding types, thrusting of unequal dimensions and earthquakes.

6. For the last 60 years 40 earthquakes were registered of the magnitude from 4 to 8, with focal depth above Moho. Most of them and of the largest magnitude originated on contacts of large structures, where there are faults, chiefly on margins of the mobile belts and on the borders of their parts.

7. Greatest seismicity was on the south margin of the Southern Tian Shan, where the differentiated tectonic movement is greatest. The magnitude of the earthquake reached 8, the focal depth 30-40 km. Many earthquakes were on the northern border of the Pamir — Kuen Lun marginal trough. Their magnitude reached 6, the focal depth 2-7 km. The largest of the above-mentioned earthquakes originated on the block structures (on the rejuvenated Variscian platform) and smaller earthquakes on the discordant folds, built by the Mesozoic and the Cainozoic rocks.

8. In other structures, whose speed of motion is less, smaller earthquakes originated. Focal depth of the earthquakes corresponded to the probable depth of the structures, and magnitude to the relative speed of motion and to the types of structures (mainly to the dimensions of faults).

Conclusions : a) The southern part of Middle Asia comprises geological structures of different types and speed of motion. b) High magnitude earthquakes originated on contacts of these structures and on contacts of their parts. c) The maximum magnitude of earthquakes on the given region, their frequency and focal depth correspond to the types of structures and relative speed of their motion.

Consequently, the southern part of Middle Asia consists of several structural belts of different grades of seismogeneity. This was taken by the author as the basis for seismic regionalization.

The paper has been published in *Izv. otd. estestv. nauk Tajik SSR Acad. Sci.*, No. 18, 1957.

66.— Prof. Riznichenko reads the paper by *V. I. Bune :* Some results of detailed study of the Stalinabad district seismic regime in 1955-1958.

With a view to study the seismic regime in the vicinity of Stalinabad a network of extremely sensitive seismic stations was built at the end of 1954.

About a thousand epicenters have been defined during the four years of observations. The average accuracy of the epicentre definition is ± 5 km. Overwhelming majority of the foci is located at a depth of 5-20 km.

Peculiarities in the epicentre locations are as follows :

a) There are some epicentral zones in which weak earthquakes have been repeating year after year.

b) The definite connection is outlined between seismicity and geological structure of the district. This connection is manifested in association with many of the epicentres with traces of the tectonic faults and in different nature of the seismic regime along the southern spurs of the Gissar Ridge and in the Tadjik Depression.

c) In the Tadjik depression, from time to time centres of sharp increase of seismic activity with a number of earthquakes burst out. (The Nurek centre 1956-1957, the Daghana-Kiik centre 1958, etc.).

Graphs of earthquake recurrences for a whole region and for each epicentral zone of the region look like straight lines (within the region of representative classes of earthquakes) with the values of angular factor being within the close limits $\gamma = 0.4\text{-}0.6$.

For the determination of seismic activity of a region both weak and strong earthquakes should be used for which the value of scatter of earthquake recurrences (R) is close to 1. The values $R > 2$ appear because of an inclusion into the totality of the earthquakes of the given region of the great number of aftershocks. In Stalinabad region the values of $R > 2$ appeared after the inclusion of the aftershocks of the Nurek earthquake 22/IX-1956 into the totality of earthquakes of the region.

The maps of seismic activity built on the basis of short-term observations (1-2 years) with small average areas (up to 300 km^2) are not representative because of the migration of the seismic activity outbursts. The maps with average areas of epicentre up to 1000 km^2 are more stable but much less detailed.

The confrontation of the seismic regime with the data of the latest crustal motions is of the greatest practical interest. The seismic data show that in the Stalinabad region motions along the principal tectonic faults, marked on the geological maps, are in progress.

The paper will be published in *Izv. Acad. Sci. USSR, Ser. Geofiz.*, 1961.

67. — *Prof. Miyamura* gives his paper : Earthquake province and its bearing on geotectonics.

The earthquake provinces in and near Japan deduced from the sympathetic occurrence in time are clearly seen in the spatial distribution of hypocenters, too. Northeastern off-shore earthquakes between the island and trench are mainly subcrustal and the hypocentral distribution continues deep into the mantle. On the other hand earthquakes on land or near coast area are, except around Tokyo, mainly supra- and intra-crustal. The tremendous number of the shocks in the former zone has ever since masked the differential nature of earthquake provinces of Japan.

The crustal earthquake of Japan has from the geotectonic point of view rather relic nature of Honsyu Geosyncline (Variscan or Alps), and the subcrustal off-shore earthquakes belong to newer Pacific phase, running along from Kurile to Marianne Is.

The value of coefficient b in Gutenberg-Richter formula $\log N = a + b\ (8\text{-}M)$ for the former was larger than that for the latter zone (C. Tsuboi). The values of the coefficients, not only b but also a for unit dM, unit period, and unit area are examined for various regions of the world. The diagram of a versus b thus obtained for many regions of the world, showed clearly a definite tendency with geotectonic nature of respective regions. Morphostructural scheme of geotectonic development by J. A. Mescherikov was extended to a cyclic one, parallel to the series of earthquakes provinces in a-b diagram.

For mid-oceanic ridges or rifts b is large but a is small. Proceeding from the oceanic small island regions to rather large island regions, the value of b decreases and the a value increases. For continental mountains and shields a and b become both small. This must be of seismogeological importance that cannot be rejected by a mere judgement of statistical test.

The paper will appear in Japanese in *Bull. Earthquake Res. Inst.*, 1961, and in English in *Journal of Physics of the Earth,* 1961.

The session is closed at 12.25.

15th SESSION

MONDAY, AUGUST 1 (morning)

Program

1. — Scientific communications: Seismological Geography and Energy of Earthquakes ; cont.

68. — *E. F. Savarensky, N. V. Kondorskaya,* and *V. L. Belotelov :* Measuring the energy of elastic waves produced by earthquakes.

69. — *I. P. Passetchnik, S. D. Kogan,* and *D. D. Sultanov :* Seismic observations in the Antarctic.

70. — *S. D. Kogan :* On the determination of energy of arbitrary shape seismic wave.

71. — *J. Vaněk* and *J. Stelzner :* The problem of the magnitude calibrating functions for body waves.

72. — *C. Lomnitz :* The recent earthquakes in Chile.

73. — *J. C. Figueroa :* New seismic chart of Mexico.

74. — *O. K. Kondratiev* and *O. G. Sorokhtin :* Seismological research works of the Soviet expedition in the Antarctic.

75. — *C. R. Bentley :* Seismic determination of ice thickness in west Antarctica.

76. — *E. Peterschmitt :* Premiers résultats séismiques obtenus par les expéditions antarctiques belges.

77. — *F. W. Lee :* Some aspects of seismology and related problems.

The session is opened at 9.05 with *Sir Harold Jeffreys* as chairman.

1. — Scientific communications: Seismological Geography and Energy of Earthquakes (cont.).

68. — *Mrs. Dr. Kondorskaya* reads the paper by *E. F. Savarensky, N. V. Kondorskaya,* and *V. L. Belotelov :* Measuring the energy of elastic waves produced by earthquakes.

In this paper the authors describe a method of measuring the energy of earthquakes in absolute units. To apply this method one should have a set of seismograms where groups of oscillations in P and S waves are quite distinct. It is assumed that all the energy of the earthquake reveals itself as P and S waves.

Having calculated the energy of these waves at the place where the seismic stations are situated, one can proceed to estimating the energy at the source. The phases P and S are shown on a seismogram as oscillation packet, the beginning of which coincides with the starting point. The energy observed during the passage of the oscillation packets is calculated by means of a special device which differentiates the amplitude of the displacement, raises the derivative to the second power and makes time integration of the resulting value.

The resulting values are made to fit the region of the source and damping, divergence and the mechanism of the source are taken into consideration. Then the value of energy of every station is averaged.

To determine the intervals between the oscillations well and to estimate probable mistakes it is desirable that a set of perfect seismograms should be provided. This method has been used to measure the energy of a number of earthquakes. At the same time data on the existence of separation borders in the Earth's core has been obtained, as well as data on the value of the damping factors of the volume waves.

The paper is published as follows :

1) In Russian in *Izv. Acad. Sci. USSR, Ser. Geofiz.*, No. 5, 1960, pp. 633-643, and No. 12, 1960.

2) In English in *Annali di Geofisica,* Vol. 14, 1961, pp. 55-64.

Dr. Båth : I found in my energy determinations (*Contributions in Geophysics : In Honor of Beno Gutenberg,* 1958, pp. 1-16) that the lack of accurate knowledge of attenuation coefficients for P and S waves was a main source of uncertainty.

Mrs. Dr. Kondorskaya : We used Gutenberg-Richter's values of attenuation coefficients.

Prof. Hales asks how the conversion from ground amplitude to incident amplitude is made. Are the conditions at the surface taken into account ?

Mrs. Dr. Kondorskaya : Reflection coefficients are taken into account, as well as angles of emergence, using Hodgson's tables.

Prof. Zátopek : Was the formula, used for calculation of magnitudes, that which is in use at Moscow ?

Mrs. Dr. Kondorskaya : Yes, surface waves with Moscow corrections were used.

Prof. Zátopek : If we consider that the differences of energy logarithms in the table given by Mrs. Kondorskaya are usually about 0.3, it is interesting to see that the earthquake No. 10 (with epicenter south of Kamchatka) gives a difference of 0.8, which seems to be rather high. Perhaps this could be in connection with certain anomalies of the earthquake waves coming from this region. In Prague e. g. there are frequently observed abnormally strong S waves from this region.

69. — Mrs. Dr. Kondorskaya then also reads the paper by *I. P. Passetchnik, S. D. Kogan,* and *D. D. Sultanov :* Seismic observations in the Antarctic.

In the period of the IGY two seismic stations were put into operation on the Antarctic continent by the Soviet Union. The station

Mirny began recording on June 1, 1956 and is in operation up till now. Seismographs of the design of Kirnos, D. P. (SVK, SGK — components NS, EW) with the magnification of the order of 1000 for the periods from 0.2 to 10 sec. and a vertical electrodynamic seismograph of the SVK-M type with the magnification about 20,000 for the periods 1.0 to 1.5 sec are installed at the station. The station Oasis Banger was in operation since July 1, 1957 till November 10, 1958. At this station records were obtained by a CBK-M seismograph and horizontal seismographs of the VEGIK type with the magnification about 2000 for the uniform band of periods from 0.2 to 3-4 sec.

During the period of their operation our stations did not record earthquakes on the area of the Antarctic continent proper. The high-frequency motion appearing sometimes on the records is most probably associated with ice movements.

The seismically active regions are the sea uplands surrounding the Antarctic continent. It is interesting to note that the line of epicenters stretches uninterruptedly from the Australian-Antarctic upland through the South-Pacific Range which is well delineated by epicentres. Earthquakes of the magnitude equal to that of earthquakes in the western part of the South-Pacific Range, between the Range and South America, did not occur. In the Atlantic Ocean the band of epicenters stretches along the South-Antilles Range joining then the epicenters of the African-Antarctic upland. The Crozet Plateau is also seismically active.

For the period of 2 years about 80 epicenters are determined in the Antarctic seismic belt.

The Antarctic seismic belt suggests the presence of some modern differentiated movements of large geological structures forming the above-mentioned uplands.

The full paper will appear in *Publications du Bureau Central Séismologique International, Sér. A, Trav. Sci., Fasc. No. 22.*

70. — *Dr. Soloviev* reads the paper by *S. D. Kogan :* On the determination of energy of arbitrary shape seismic wave.

Well-known methods for determination of seismic wave energy (Zöppritz-Wiechert formula for body waves and Jeffreys one for surface waves) are valid strictly speaking only for harmonic waves. Applications of these formulae to arbitrary shape wave produce appreciable errors. We propose simple formulae for calculation of energy of arbitrary finite packet of seismic waves. In the case of surface Rayleigh wave packet the energy is :

$$E = 2\pi R \sin\Delta\, c^2 \rho\, A_1 \int_0^{\tau} U_x(t,O)\, V_z(t,O)\, dt \qquad (1)$$

where

R = radius of the Earth

Δ = epicentral distance

c = velocity of Rayleigh wave

ρ = density of Earth

A_1 = dimensionless constant depending on the elastic parameters of media. In the case $\sigma = 1/4$ $A_1 = 4{,}717$

U_x = horizontal displacement in the period of observation

V_z = vertical displacement velocity

τ = duration of surface wave record on seismogram

The energy of bodily wave packet is calculated according to the formula :

$$E = 2\pi R^2 a\rho \frac{\sin \Delta \sin e_0}{\cos e_h \left| \frac{de_h}{d\Delta} \right|} \int_0^{\tau} V^2 \, dt \qquad (2)$$

where

a = velocity of bodily wave

V = velocity of displacement in incident wave

e_o = angle of emergence

e_h = angle, which the ray leaving the focus at the depth h makes with level surface through the focus

In the formulae (1) and (2) we have neglected the damping effect.

The term $\frac{\sin \Delta \sin e_0}{\cos e_h \left| \frac{de_h}{d\Delta} \right|}$ characterizing the divergence of bodily seismic wave can be calculated without difficulty.

The relation (1) or (2) permits us to calculate more exactly the seismic wave energy and opens the way for construction of the designs for recording seismic wave energy.

The paper has been published in the following journals :

1) *Izv. Acad. Sci. USSR, Ser. Geofiz.*, No. 5, 1960, pp. 644-652.

2). *Acta Geophysica Sinica,* Vol. 8, No. 1, 1959, pp. 31-39.

71.— Prof. Zátopek presents the paper by *J. Vaněk* and *J. Stelzner :* The problem of the magnitude calibrating functions for body waves.

The calibrating functions $\beta(\Delta)$ for determining the earthquake magnitude M defined by the relation

$$M = \log (A/T) + \beta(\Delta) + \Sigma\, \delta M$$

(A = amplitude in μ, T = period in sec, Δ = epicentral distance in degrees, $\Sigma\, \delta M$ = corrections) were deduced for body waves by means of a relatively large set of homogeneous observations (499 for PH, 166 for PV, 250 for PPH and 520 for SH) of four European stations (Prague, Jena, Collmberg, Potsdam). The combination of data of the latter stations was enabled by estimating the corresponding station corrections of individual waves in relation to Prague. According to divergent scales for body and surface waves, respectively, only magnitudes from body waves based on the first approximation of the calibrating functions (1) were considered. A similar divergence between the scales for P- and S-waves was found. Therefore average magnitudes of the respective wave were used for deducing the second approximation $\beta(\Delta)$ of the calibrating functions. Due to a sufficient number of observations the fine structure of the calibrating functions could be investigated. A clear oscillatory character of calibrating functions in several distance intervals was observed, this phenomenon being connected to the structure of the Earth's mantle. The mean error of a single observation in β was estimated to be in average $\pm$ 0.14 of magnitude unit. Using the calibrating functions deduced the precision of determining the magnitudes from body waves was thus increased three times in comparison to original calibrating functions β (Δ).

Reference : (1) J. Vaněk and A. Zátopek : Magnitudenbestimmung aus den Wellen P, PP und S für die Erdbebenwarte Prag, *Travaux Inst. Géophys. Acad. Tchécoslov. Sci.*, No. 26, 1955, pp. 91-120.

The paper presented has been published in *Annali di Geofisica,* Vol. 13, No. 3-4, 1960, pp. 393-407.

A closely related subject (Bestimmung der Magnitudengleichungen für Jena) was recently studied by the same authors and published in *Gerlands Beiträge zur Geophysik,* Bd 68, H. 2, 1959, p. 75-89.

Sir Harold Jeffreys : It is very interesting that the amplitudes of P and S near 20° have been determined. In the interval 15°-25° the times of arrival do not decide between a cubic curve and two intersecting straight lines, but as amplitudes are related to $d^2t/d\Delta^2$ they should decide the question.

Prof. Richter : The values of $q = \log (A/T)$ determined at Pasadena were necessarily in large part based on seismograms at that station. However, every effort was made to use amplitudes and periods reported from other stations, in preparing the revised residuals, plotted against distance and depth.

The chairmanship is handed over to *Prof. Press.*

72. — *Prof. Lomnitz* gives his paper : The recent earthquakes in Chile.

Prof. Lomnitz demonstrates in a number of slides the destruction in Chile during the earthquakes in May, 1960. No detailed summary or reference is available.

Dr. Soloviev : What are the maximum and average heights of the tsunamis ? What is the size of the region affected by the waves ?

Prof. Lomnitz : The maximum height of the tsunami (near the epicenter) was approx. 12 meters. The details will be communicated at a special meeting devoted to tsunamis (16th Session).

Father Ingram : Is there evidence of normal or transcurrent faulting ?

Prof. Lomnitz : There does not seem to be evidence of any fault as yet, so far as I have found. I hope to discuss this question more fully at a later meeting (22nd Session).

73. — *Mr. Figueroa* presents his New seismic chart of Mexico.

Due to the fact that seismic data has been published since 1909 in Mexico, this work includes a period of 50 years (1909-June 1959) for instrumental recording in which 18,211 movements have been registered.

In this Seismic Chart the delimitation of the following zones is confirmed : active, less active and those in which shocks are rare or unknown.

Location of shocks (numerically appearing in chronological order) was made with instrumental data of Tacubaya and 10 auxiliaries : Comitan, Chihuahua, Guadalajara, Leon, Manzanillo, Mazatlan, Mérida, Oaxaca, Puebla and Veracruz.

The conventional signs used in the chart express margins of focal depth and magnitude of the most important shocks that occurred in each epicentral region.

In order to make the trace of the most important faults, the epicentral line-up, the characteristics of after-shocks and the geological evidence were taken into account.

Tables and curves of seismic frequency, as well as liberation of accumulated energy, are contained in the text showing, therefore, that 43 % of the activity took place in parallels 15° and 16° N, limited by meridians 97°, 98°, 99° W of Greenwich. The maximum liberation of dissipated energy took place in epicentres which geographical coordinates are between 19° N and 103° W of Greenwich ; this dissipation reached a value of 10^{230839} in 50 years. On the other hand, the total dissipation in the Mexican Republic was 10^{240928}, considering shocks of magnitude IV and greater.

General data is given regarding destructive movements which occurred in the Mexican Republic. In order to make it clearer, the data corresponding to the basin of the Valley of Mexico and that corresponding to Lower California have been separated from the data of the rest of the country.

Considering the influence of soft underground in the increase of seismic effects that is of such importance in the Mexican Capital, an account is given of the movements felt in Mexico City since 1900 to June 1959, giving grades in intensity and the limits to which acceleration could have varied in each case.

This work includes a Seismic Bibliography of Mexico.

The map is published under the title "Carta Sísmica de la Repûblicana Mexicana (con datos hasta 1959)" in *Anales del Instituto de Geofísica, U.N.A.M.*, Vol. 5, Mexico 1959, pp. 37-162.

Father Ingram : May I ask for the direction of fault motions ?

Mr. Figueroa : The main faults have the same tendency as San Andreas' fault and the others in California.

74.— *Prof. Karus* reads the paper by *O. K. Kondratiev* and *O. G. Sorokhtin :* Seismological research works of the Soviet expedition in the Antarctic.

1. In 1956-1958 the Soviet Complex Antarctic Expedition was conducting investigations to determine the thickness of the ice cover in Antarctica along the route Mirny—Pole of Inaccessibility and some other regions. The total number of seismic soundings reached 121, of which 28 fall on central regions. The method of reflected waves in its high-frequency modification has been mainly applied. The methods of investigations in coastal regions were reported at the 5th CSAGI Assembly in Moscow.

2. The methods of investigations in central regions possess some specific particuliarities owing to the high intensity of irregular disturbances hampering the distinguishing of reflections. The difficulties of recording reflected waves have here been overcome by increasing the depth of blast holes up to 40-60 m and the frequency of the filtering equipment (the frequency of the left section is 150 c/s).

3. P,S and surface waves connected with the upper strata have been recorded. The seismograms distinguished a whole group of reflected waves. To determine their nature special observations by the method of reflected waves and the correlation method of refracted waves were conducted. The first reflected wave which is not distinguished everywhere, corresponds to the surface of a moraine-bearing layer of ice. The second reflected wave corresponds to the surface of crystalline rocks. As the result of the processing of the travel-time curve of this wave the data on the thickness of the ice cover and propagation velocity of waves in the surface medium have been obtained.

4. The glacier profile obtained from the profile Mirny-Pole of Inaccessibility enables the worker to distinguish four principal zones :

1) Zone of continental shelf (up to 50 km off shore);

2) Zone of the peripheral block structure (Galitzin subglacial mountains from 50 to 550 km off shore);

3) Zone of the buried plain (Schmidt subglacial plain from 550 to 1,000 km);

4) Zone of central mountainous structures (Gamburtsev subglacial mountains from 1,000 to 2,000 km).

From the total profile length of 2,100 km, 1,800 km fall on the areas where basic rocks are deposited above sea level. The maximum registered altitude of the basic rocks is +3,000 m, the minimum —1,000 m, the mean altitude of the whole of the profile is 800 m above sea level. The maximum registered thickness of the glacier is 4,000 m, the mean thickness of the glacial cover is 2,200 m. Taking into account the isostatic levelling of the continent, its mean altitude above sea level before the ice-covering could be thought equal to about 1,500 m, which seemed to account for the formation of such colossal masses of the continental ice.

The paper has been published in *Izv. Acad. Sci. USSR, Ser. Geofiz.*, No. 3, 1960, and in *Vestnik Acad. Sci. USSR,* No. 3, 1960.

75. — *Dr. Bentley* gives his paper : Seismic determination of ice thickness in west Antarctica.

Seismic observations made during the course of oversnow traverses in west Antarctica are described. The equipment comprised a Texas Instrument 7000B Seismograph System and a variety of geophones, both vertical and horizontal, with various frequency characteristics. The wide frequency range of the system was found very useful but AGC and mixing were seldom used. A standard explosive charge of 1 pound was normally buried in a shallow hole. The reflection frequency was generally around 120 cycles per second. When conditions were good, 6 of the 24 geophones were oriented horizontally, recording reflected shear wave energy at a number of stations. Short refraction shooting provided detailed knowledge of near surface velocity variations for correcting reflection times and for comparison with changes in other physical properties of the firn. Prolonged surface noise, the exact nature of which is not understood, was the major obstacle to successful results. This noise varies with the season, and is completely incoherent. Deep shot holes appear to be the only answer to this problem. A very weak reflection arriving shortly before the main echo from the ice-rock interface was recorded whenever noise conditions permitted. General agreement with Robin's laboratory determined relations between velocity, density, and temperature was found, with a slight but real divergence in the velocity vs. density curve.

The paper has not yet been fully prepared for publication.

Dr. Båth : Do the formulas relating amplitude with distance, you have given, represent the combined effect of geometrical spreading and of absorption or have you tried to separate these effects ?

Dr. Bentley : The observations were insufficient to permit a reliable separation of these two effects. Absorption is probably quite small.

76. — *Mr. Peterschmitt* reports on « Premiers résultats séismiques obtenus par les expéditions antarctiques belges ».

No summary or reference is available.

77. — *Mr. Lee* gives his paper : Some aspects of seismology and related problems.

As a part of a seismological program, there is proposed the measurement of ground stresses. The study of such measurements will serve for the purpose of locating dangerous conditions impending to the occurrences of earthquakes. Apparently there are other fields of force associated with earthquakes heretofore not fully evaluated.

The session is closed at 12.20 .

16th SESSION

MONDAY, AUGUST 1 (afternoon)

Program

1. — Scientific communications : Tsunamis and Storm Surges.

78. — *J. P. Rothé :* Introduction au symposium ; historique, les « Annales pour l'étude des raz de marée ».

79. — *E. B. Roberts :* On a seismic sea wave warning system.

80. — *L. M. Murphy :* Discussion of tsunami of Chile.

81. — *C. Lomnitz :* Les tsunamis chiliens.

82. — *E. F. Savarensky* and *S. L. Soloviev :* Studies of tsunami in the USSR.

83. — *A. G. Galanopoulos :* Tsunamis observed on the coasts of Greece from antiquity to present time.

84. — *K. Wadati* and *T. Hirono :* On the tsunamis, storm surges and their warning systems in Japan.

85. — *R. Takahasi :* Recent studies in Japan on tsunami and storm surges.

Adoption of resolution.

This symposium is held together with IAMAP and IAPO. It is opened at 14.30 with *Secretary General Laclavère* as chairman.

1. — Scientific communications : Tsunamis and Storm Surges.

78. — *Prof. Rothé* reports on the organization of this symposium : Introduction au symposium ; historique, les « Annales pour l'étude des raz de marée ». The presentation, given in French, is translated into English by the Chairman.

Le Professeur Rothé rappelle les faits qui ont motivé l'organisation du symposium. Le Comité exécutif de l'Organisation Météorologique Mondiale (OMM) avait, au cours d'une session tenue à Genève en 1957, examiné l'opportunité d'établir un service international concernant la formation et le mouvement des raz de marée. Une résolution avait été adoptée par l'OMM qui a entrepris une enquête d'ordre général. L'U.G.G.I., consultée, a décidé d'étudier au cours de l'Assemblée générale d'Helsinki, les principaux points suivants : origine, propagation, distinction entre les raz de marée d'origine séismique et d'origine météorologique, fonctionnement des services d'alerte et extension éventuelle de ces services.

Le Professeur Rothé souligne la distinction fondamentale à faire entre les raz de marée proprement dits (« tsunamis ») d'origine séismique et les vagues de tempête (« storm surges ») d'origine météorologique, et rappelle que depuis longtemps les raz de marée ont fait l'objet de recherches approfondies. Des systèmes d'alerte fonctionnent déjà dans plusieurs pays. La catastrophe qui s'est produite le 22 mai 1960 au Chili donne au symposium un tragique caractère d'actualité et les faits recueillis à cette occasion doivent permettre de procéder à une amélioration des systèmes d'alerte actuellement existants.

M. Rothé rappelle encore que, à la suite d'un vœu présenté par M. Fichot à l'Assemblée générale de Prague en 1927, une commission pour l'Etude des Raz de Marée avait été constituée par l'U.G.G.I. Cette commission a publié 4 fascicules intitulés « Annales de la Commission pour l'Etude des Raz de Marée ». Ces annales contiennent plusieurs articles scientifiques, par exemple l'article du Captain N. Heck, catalogue de 224 raz de marée importants. Une documentation sur les envahissements du littoral avait commencé à être établie. Une bibliographie à coller sur fiches avait été entreprise. Monsieur Rothé se demande s'il y aurait lieu de reprendre la publication de ces Annales.

Monsieur Laclavère ajoute que le résultat de l'enquête entreprise par l'OMM a été publiée dans la chronique de l'U.G.G.I. Une liste des organisations s'intéressant à la génération et à la propagation des raz de marée a également été insérée dans la chronique.

Prof. Proudman : The cessation of the publication of the *Annales pour l'étude des raz de marée* was probably due to the death of M. Hubert, the editor of the Annales. — But the articles in the Annales were chiefly of a descriptive nature, describing damage done by storms and seismic surges. They were not chiefly of the type of scientific investigation now carried out with a view to forecasting such surges.

Mr. Gougenheim : Je pense que c'est à la suite de la mort de M. Hubert que la publication des Annales de la Commission pour l'étude des raz de marée a été interrompue. Quelques archives sont conservées par le Directeur du Service Hydrographique de la Marine à Paris.

79. — *Captain Roberts* gives his report : On a seismic sea wave warning system.

Following the damaging tsunami of April 1, 1946, the Coast and Geodetic Survey organized a seismic sea wave warning system which has since functioned without failure for the warning of the Hawaiian Islands and the West Coast of the United States. Cooperation has been received from the Philippines, Japan, Peru, and Chile. The latter countries have been informed of disastrous conditions but have not been given specific predictions of wave arrival times.

The system has not undertaken to provide advance predictions of wave heights. Deaths in several places due to the May 23, 1960 tsunami have indicated a need for the specific prediction of wave effects, and in consequence the Coast and Geodetic Survey will undertake research studies of tsunami effects. The United States will gladly discuss the extension of the organization with Pacific area countries for the better dissemination of specific warnings to any such countries.

The complete report has not been submitted for publication.

80. — *Mr. Murphy* presents his paper : Discussion of tsunami of Chile.

No summary or reference available.

Prof. Lomnitz remarks that there is a noticeable lack of tidal wave warning stations between the coasts of Chile and the Hawaiian Islands.

Ing. Gershanik : I have the impression that tsunamis take place when the following three conditions are given : 1) The epicenter must be placed in the sea ; 2) The earthquake must be strong enough ; 3) The mechanisms of the earthquake must have some special features ; perhaps a large fault, more than 100 km long. — I think therefore that in order to improve methods of predicting tsunamis, it is advisable to investigate the special features of the earthquakes that have produced them in the past.

Dr. Shaw : As Fiji had not been included in the list of stations mentioned by the speaker, Mr. Murphy, it might interest delegates to know that warning was received in Suwa that the seismic sea wave might be expected at 22.00 hours and that it arrived within ten minutes of that predicted time. Fortunately it was low tide at the time and the total amount of water level charge was small, being between two and three feet.

Prof. Wadati : As a delegate of Japan, I should like to express our thanks to USCGS for their very significant work on tsunami warning service. There might be many things to be discussed among delegates of countries concerned on this occasion, and I wish to suggest to have a meeting for this purpose after this symposium.

81. — *Prof. Lomnitz* gives his paper : Les tsunamis chiliens.

No summary is available. A description of the tsunami on the Chile coast has been given by A. A. Taraba : El maremoto del 22 de mayo de 1960, *Boletin Informativo del Departamento de Navegacion e Hidrografia de la Armada,* Año 16, No. 56, Valparaiso 1960, 11 pp.

Captain Roberts : The U.S. is investigating the feasibility of using automatic telemetering equipment at wave detection stations.

82. — *Dr. Soloviev* reads the paper by *E. F. Savarensky* and *S. L. Soloviev :* Studies of tsunami in the USSR.

Les séismes qui provoquent des tsunamis destructeurs en URSS ont leur origine principalement à l'est de la côte du Kamchatka et des îles Kuriles du sud. Il y a approximativement 3-4 ondes catastrophiques chaque siècle au nord et au sud de la région.

Le service des tsunamis de l'URSS a commencé de travailler récemment. Il est attaché au service hydrométéorologique du pays.

Le service comprend trois stations spéciales dont la partie principale est la cellule séismologique.

Ces stations sont : Youjno-Sakhalinsk, Kurilsk, Petropavlovsk. On veut installer d'autres stations dans le futur. Les stations sont équipées de séismographes spéciaux construits par D. Kirnos et A. Rykov. Chaque installation contient deux instruments : l'un pour la détermination de l'azimuth de l'épicentre, l'autre pour la détermination de la distance épicentrale (2).

Deux caractéristiques sont choisies pour distinguer les séismes avec tsunamis et sans tsunamis.

Le premier caractère est la situation de l'épicentre. Deux zones épicentrales favorables au développement des tsunamis ont été proposées par G. I. Popov (1).

L'autre caractère est la magnitude du séisme. S. Soloviev et N. Shebalin ont proposé que seulement les séismes de magnitude égale ou supérieure à 7-7½ peuvent provoquer des tsunamis assez grands. Des nomogrammes spéciaux ont été construits pour estimer la menace du tsunami à partir de la différence S-P et de l'amplitude des ondes P et S (3).

Toutes les opérations doivent être terminées très vite et l'alerte doit être donnée quelques minutes (5 à 10) après l'arrivée des ondes P à la station.

On a étudié l'influence du relief littoral sur l'amplitude des vagues océaniques. Le risque des tsunamis est estimé pour les parts différentes de la côte pacifique et la carte correspondante est préparée (2).

Références :

1) Popov G. I., *Izvestiya Akademii Nauk, seriya geofizitcheskaya,* No. 8, 1959.
2) Savarensky E. F., *Vestnik Akademii Nauk,* No. 9, pp. 11-15, 1958.
3) Soloviev S. L., Shebalin N. V., *Izvestiya Akademii Nauk, seriya geofizitcheskaya,* No. 8, 1959.
See also *Sov. Bull. Seism., Akad. Nauk SSSR,* No. 9, 1961.

Mr. Jensen : What kind of seismic waves do you use in your direction determinations ?

Dr. Soloviev : P waves.

83.— Prof. Galanopoulos presents his paper : Tsunamis observed on the coasts of Greece from antiquity to present time.

Des 41 tremblements de terre suivis de raz de marée sur les côtes de la Grèce au cours de la période 600 a. C. - 1958, 16 seulement ont été accompagnés de tsunamis réellement endommageants ou destructeurs. Ce nombre est trop petit par rapport aux 613 séismes connus avec $I_0 \geqslant$ VI de l'échelle Mercalli-Sieberg, ou aux 281 séismes avec $I_0 \geqq$ VIII, qui eurent lieu dans la même période ; la proportion en est respectivement 1 : 15 et 1 : 18. Pendant la période 1801-1958, relativement bien connue, eurent lieu 482 séismes avec $I_0 \geqslant$ VI et 170 avec $I_0 \geqq$ VIII. Les tremblements de terre suivis par des tsunamis montent à 20 ; de ces tsunamis 6 ont produit des dégâts ou furent destructeurs. La proportion pendant cette période devient respectivement 1 : 24 et 1 : 28. La fréquence pour cette dernière période en est 1 : 8 par an pour le nombre total des tsunamis et 1 : 26 par an pour les tsunamis qui ont produit des dégâts ou désastres. Il résulte assez clairement de cette statistique que les raz de marée sur les côtes de la Grèce ne constituent pas un danger sérieux contre lequel un système d'alerte devrait être établi.

Il est remarquable que malgré le grand nombre de baies et la haute fréquence des secousses violentes dans la région des Iles Ioniennes, les raz de marée correspondants sont bien rares et de nature inoffensive. Au contraire, dans le Golfe Maliakos et particulièrement dans le Golfe de Corinthe les raz de marée y correspondants sont relativement nombreux et assez destructifs. Il faut noter que de grandes masses de matériaux incohérents sont annuellement transportées par les rivières, qui se jettent dans les golfes susnommés, particulièrement dans la région d'Aeghion. Ce fait et l'association des ruptures de câbles et de grands éboulements avec des secousses destructives dans le Golfe de Corinthe et dans la Mer Ionienne plaident en faveur de l'idée selon laquelle au moins quelques-uns de ces raz de marée furent déclenchés par des glissements des matériaux non consolidés.

Il n'y a pas d'évidence positive à l'égard du mécanisme causant le déclenchement des tsunamis dans la Mer Egée. Pourtant, l'occurrence des séismes suivis de raz de marée près de la fosse de Saros et du sillon profond de la Crète et spécialement l'entraînement par répliques de moindre intensité, quelques heures plus tard des raz de marée de la même amplitude que ceux entraînés par la secousse principale, invoquent une explication plutôt par des glissements sous-marins que par des déplacements de blocs sous-marins ou d'autres agents directement liés au tremblement de terre.

The full paper has been published in *Annali di Geofisica,* Vol. 13, no. 3-4, 1960, pp. 369-386.

Mr. Ringbom : Do you have any archaeological evidence for your remarks on Acropolis ?

Prof. Galanopoulos : Acropolis being at the top of the volcanic cone, in the middle of the Metropolis Island, was completely destroyed by lava ; there is no possibility for any archaeological evidence.

84. — *Prof. Wadati* presents the paper by *K. Wadati* and *T. Hirono :* On the tsunamis, storm surges and their warning systems in Japan.

Japan is a country which is often attacked by earthquakes and typhoons, and since old times she has suffered enormous damage from tsunamis and storm surges accompanied by them.

Consequently in Japan many studies have been made on these phenomena and also the Japan Meteorological Agency is making every possible effort for issuing the warnings of these, from the standpoint of prevention of disasters.

1) Large tsunamis cause a great deal of damage to the coasts of Japan of the Pacific side, especially to bays of Rias type. The warning service for tsunamis has been conducted since 1952. For this purpose, by the J.M.A. are established the tsunami decision centers, in which the operations are done for deciding in a short time on the epicenter, focal depth, scale of earthquakes and on the scale of tsunamis, etc., aiming at the issue of warnings within about 20 minutes after the earthquakes. For reading of seismic records, for communication of observed data, rapidity of tsunami decision and for operations based on these, incessant effort is made to find new devices. The warnings are broadcast to the general public and also transmitted domestically and to neighbouring foreign countries as well as to the tsunami center at Hawaii. In the cases of the Tokachi-oki earthquake (off Hokkaido) and the Etoforu earthquake in 1952, tsunami warnings were issued with success.

2) Storm surges are apt to occur chiefly in shallow inland (recessed) bays, and the damage is concentrated on large cities at the innermost recess of such bays.

The service of storm surge warning has been conducted since 1952, and the warnings are issued from meteorological observatories at various places, forming a link in the chain of meteorological warnings. In preparing a warning the anomalous heights of tidal wave are calculated by means of the formula proper to each harbor or bay taking account of the typhoon path, atmospheric pressure and wind velocity. The contents of storm surge warnings are revised in accordance with the actual state of tidal height observed successively. In view of the frequent occurrence of damage from storm surges in recent years, all efforts are made at present to equip more fully the observational facilities for storm surge in principal harbors and bays and to collect more materials for preparation of the warnings.

The paper is expected to be published in one of the publications, issued by the Japan Meteorological Agency.

85. — *Prof. Takahasi* gives his paper : Recent studies in Japan on tsunami and storm surges.

No summary or reference is available.

Remaining papers (by J. R. Rossiter, D. L. Harris, G. W. Lennon, H. P. Schmitz, W. Hansen, R. O. Reid, R. Sneyers) are postponed until Tuesday afternoon, August 2. As these papers are of a purely oceanographic interest, the proceedings are published by IAPO in their *Procès-Verbaux, No. 8, General Assembly at Helsinki, 1960.*

A resolution on tsunamis is agreed upon, of which the text is given in the 24th Session.

The session is closed.

17th SESSION

MONDAY, AUGUST 1 (afternoon)

Program

1. — Scientific communications : Constitution of the Continental and Oceanic Crust; cont.

86. — *F. Press :* Recent results in the study of crustal structure.

87. — *M. Båth :* Crustal structure of Iceland.

88. — *J. Oliver, G. Sutton,* and *M. Ewing :* Some results of the IGY long-period seismology program - oceanic crust.

89. — *A. G. Averianov, P. S. Weizman, E. I. Galperin, S. M. Zverev, I. P. Kosminskaya, K. M. Krakshina, G. G. Michota,* and *I. V. Tulina :* Deep seismic soundings carried out during the IGY in the zone of transition from the Asiatic continent to the Pacific Ocean.

90. — *J. Hennion* and *J. Ewing :* Seismic refraction measurements in the southeastern Caribbean Sea.

91. — *E. T. Bunce* and *D. A. Fahlquist :* New seismic observations across the Puerto Rico Trench.

92. — *D. A. Fahlquist :* Preliminary results of seismic investigations in the Western Mediterranean Sea.

93. — *I. I. Popov :* The dispersion of the long-period Love waves along the continental and oceanic paths from Indonesia to the Crimea.

94. — *M. H. P. Bott :* Gravity anomalies over granites and their relation to the continental crust.

The session is opened at 14.30 with *Sir Harold Jeffreys* as chairman.

1. — Scientific communications : Constitution of the Continental and Oceanic Crust (cont.).

86. — *Prof. Press* gives his paper : Recent results in the study of crustal structure.

There are many advantages in the combined use of three methods for the study of the earth's crust in a given region : seismic refractions, surface wave phase velocity, and gravity. Only by this approach can the fine details of crustal structure be revealed. The standard phase velocity curves are revised to take into account recent refraction results in South Africa and the Gutenberg low-velocity zone of the upper mantle. Restrictions on the use of the phase velocity method alone are discussed.

The three methods were applied in the California-Nevada region. When the structure determined by the refraction method is used to compute theoretical Rayleigh wave phase velocities and gravity anomaly, discrepancies are found with the observed values which can be resolved by reducing the mean shear velocity and density in the crust. It is probable that this reduction is limited to the intermediate crustal layer, and several modifications consistent with all three exploration methods are discussed.

Mr. Dorman : Is it possible that the unusually low shear velocities in the upper mantle required by the oceanic surface wave data are related to the relatively small water depth for the path ?

Prof. Knopoff: What is the basis for assumption of S wave velocity for the structure corresponding to the Easter Island to Pasadena path ? Is it not possible that regions of high heat flow correspond to different Poisson's ratios since it is possible there may be local melting, as reported by Press and Ewing ?

Prof. Press : Both questions may be related. The answer to the first is yes, it is possible that the shallower water depth is representative of a mantle different from that under the Pacific Ocean basin. The assumed ratio of P to S velocity is that found in common crystalline rocks. Prof. Knopoff's suggestion is indeed possible.

Mr. von Herzen : It should be mentioned that the seismic refraction profiles at sea on the East Pacific Rise often do not detect an 8.0 (or greater) km/sec layer, but only detect a maximum of about 7½ km/sec. This may explain some of the discrepancy between the observations and an assumed normal oceanic crustal structure in the model.

Mr. Romberg : Do I understand that the reverse coverage in the California-Nevada refraction shots precluded the possibility of the observed velocity of 7.6 km/sec being due to dip in a surface whose true velocity was 8.1 km/sec ?

Prof. Press : Yes, also the 8.1 km/sec arrivals beyond 360 km substantiate the interpretation. The 7.6 km/sec layer has also been found by others in different parts of the Great Basin.

Dr. Gaskell : Does the point you make that the Easter Island Ridge structure is more like that of the Atlantic than the Pacific mean that you believe the structure of the Atlantic differs from that of the Pacific ?

Prof. Press : Yes, so far as upper mantle is concerned. Dr. Aki will speak to this point in his presentation (27th Session).

87. — *Dr. Båth* presents his paper : Crustal structure of Iceland.

A report is given of the results of a seismic field investigation in 1959 of the crustal structure of Iceland. Explosions were performed at 30 m water depth in Graenavatn, a crater lake in south-west Iceland, and recordings were made with a 12-channel refraction apparatus at a number of stations along two profiles across Iceland, one profile (CP) across the center of the island and another profile (WP) in the western part. A three-layered crust was found, a top layer of lava and volcanic ash and two basaltic layers. The longitudinal wave velocities are 3.69, 6.71, and 7.38 km/sec resp. and the layer thickness 2.1, 15.7, and 10.0 km resp. The total crustal thickness down to the Mohorovičić discontinuity is around 27.8 km. Direct waves through the various layers as well as reflected waves are used in the study. Longitudinal guided waves, propagated by multiple reflections in the lava layer, were found to distances over 100 km. As a consequence of the large velocity contrast between the lava layer and the first basaltic layer, more than 83.5 per cent of the original seismic energy remains in the lava layer, leaving only a few per cent to penetrate deeper. Amplitude attenuation coefficients have been determined, which are about twice as large for the central profile (CP) as for the western profile (WP). The main reason for the strong attenuation along CP is scattering of the waves in the inhomogeneous and heavily fractured crust. The seismic efficiency of the explosions, all carried out in the same way, varies in the mean by 20-25 per cent, as evidenced by the records of the Reykjavik seismograph station.

The paper has been published in the *Journal of Geophysical Research,* Vol. 65, No. 6, 1960, pp. 1793-1807.

Dr. Bott asks for possible evidence from gravimetric observations on Iceland.

Dr. Båth : Gravity observations on Iceland have been published by T. Einarsson (*Soc. Sci. Islandica,* Vol. 30, 1954, 22 p.). They demonstrate that our western profile is almost tangential to the curves for gravity anomalies, whereas the central profile is not. The Bouguer anomalies are roughly concentric to the island with negative values in the center (minimum —35 mgals) and positive on the coasts (around +40 to +50 mgals).

88. — *Dr. Oliver* reads the paper by *J. Oliver, G. Sutton,* and *M. Ewing :* Some results of the IGY long-period seismology program — oceanic crust.

During the International Geophysical Year, 1957-1958, a number of three-component long-period seismographs were operated at island or near-coastal stations. These stations were favorably situated with respect to seismic belts so that many shocks were recorded for which the paths were almost entirely across deep ocean basins. In such cases some of the kinds of long-period waves recorded were : Rayleigh waves with periods greater than about 14 seconds and corresponding to the fundamental Rayleigh mode ; Love waves with periods greater than about 14 seconds and corresponding to fundamental Love mode (G waves) ; surface waves with periods between about 20 and 6 seconds appearing at times on all three components of ground motion with approximately equal amplitudes and equal periods ; P-waves, apparently guided by the crustal layers and occurring as dispersed trains for shocks at moderate distances from the station.

In general, these waves are very similar for similar oceanic paths but minor differences do appear and these differences may be used to deduce small changes in crustal structure from path to path.

The paper is in preparation for publication.

Prof. Miyamura : Using the long-period seismograph observations at Tsukuba during IGY Dr. T. Santô, ERI, Tokyo, obtained Rayleigh wave dispersions along the oceanic paths to Japan from various parts of the world (*Bull. Earthq. Res. Inst.,* Vol. 38, 1960, pp. 219-240 and pp. 385-401 ; further, Vol. 39, 1961, pp. 1-22). Those along the paths across the northern Pacific are all very well coincident with a purely oceanic curve, and when the paths shift to the west, they gradually become near to a purely continental curve. On the other hand, the dispersion curves along the oceanic trench to Japan are distinctly different and do not lie between purely oceanic and continental curves. They are very steep and cross the ordinary dispersion between the purely oceanic and purely continental ones. This does not seem to be explained by the effect of the depth of water but indicates a peculiar crustal structure along the trenches.

89. — *Mrs. Dr. Kosminskaya* reads the paper by *A. G. Averianov, P.S. Weizman, E.I. Galperin, S.M. Zverev, I.P. Kosminskaya, K. M. Krakshina, G. G. Michota,* and *I. V. Tulina :* Deep seismic soundings carried out during the IGY in the zone of transition from the Asiatic continent to the Pacific Ocean.

No summary is available.

The paper will be published in *Publications du Bureau Central Séismologique International, Sér. A, Trav. Sci., Fasc. No. 22.*

Sir Harold Jeffreys : In the Jeffreys-Bullen tables the velocity of P at short distances was partly based on one European earthquake and many Japanese ones, and is 7.8 km/sec. The European data have been found to have a systematic error, and the correct European velocity is about 8.1 km/sec. This velocity agrees with N. America and has been found in most of the oceans. But later discussions have still given 7.8 km/sec in Japan. It would be interesting to know the extent of the region where this velocity holds.

Prof. Riznichenko, in reply : There has not been observed any definite dependence of the Moho velocity on the type of the crust (continental, intermediate, oceanic). On several portions of the Pacific oceanic plateau, near Kurile Islands-Japan, we have, on the contrary, a much higher velocity : 8.6 km/sec. It is defined from reverse and overlapping measurements, and is thus not an apparent velocity.

90. — *Mr. Hennion* presents the paper by *J. Hennion* and *J. Ewing :* Seismic refraction measurements in the south-eastern Caribbean Sea.

A number of seismic refraction stations were completed in the southeastern Caribbean Sea across the Curacao Ridge, in the Los Roques and Bonaire trenches and adjacent to the offshore islands of Curacao and Bonaire in the Netherlands Antilles. Several airborne magnetometer surveys through the area have been made and a series of submarine gravity determinations are available. The seismic refraction measurements show a very thick sedimentary complex beneath the Curacao Ridge. In the Los Roques and Bonaire trenches the mantle is determined to be approximately at the same depth, about 18 km. The Bonaire Trench contains a much greater overburden of low-velocity material than the Los Roques Trench. The Netherlands Antilles Ridge between the Los Roques and Bonaire trenches is supported by a steep rising high-velocity crust. Near the islands the crust is quite shallow but deepens rapidly seaward. Correlation with magnetic and gravity measurements in the region are discussed. Geological and geographical relationships with adjacent areas are considered.

Results of geophysical investigations in the eastern Caribbean by the Lamont Geological Observatory were published in *Bull. Geol. Soc Amer.*, Vol. 68, 1957, pp. 897-912 ; Vol. 63, 1957, pp. 359-378, and in *Physics and Chemistry of the Earth,* Pergamon Press, Vol. 3,1959, pp. 17-109.

91. — *Miss Dr. Bunce* presents the paper by *E. T. Bunce* and *D. A. Fahlquist :* New seismic observations across the Puerto Rico Trench.

Geophysical studies were conducted in the area north of Puerto Rico during May and June 1959. Scientists and research vessels of the Woods Hole Oceanographic Institution, Lamont Geological Observatory and Hudson Laboratories of Columbia University, and the Department of Oceanography, Texas A. and M. College participated in the program.

The seismic studies included a continuous seismic section across the Puerto Rico Trench and the outer ridge along longitude 66° 30' W. Additional profiles were made, normal to and intersecting the north-south profiles.

Interpretations of these data are in general agreement with the crustal section proposed by Talwani et al (1959) [1]. The new measurements emphasize the complex structure of the material overlying the mantle in this region.

1) M. Talwani, G. H. Sutton, and J. L. Worzel : A crustal section across the Puerto Rico Trench, *Journal of Geophysical Research,* Vol. 64, No. 10, 1959, pp. 1545-1555.

92. — *Dr. Fahlquist* gives his paper : Preliminary results of seismic investigations in the Western Mediterranean Sea.

Seismic refraction studies were carried out in the Western Mediterranean Sea in the summer of 1958 by scientists aboard R/V ATLANTIS of the Woods Hole Oceanographic Institution and R/V VEMA of Lamont Geological Observatory. In the summer of 1959 four additional seismic stations were occupied by R/V CHAIN of the Woods Hole Oceanographic Institution and the R/V WINNERETTA-SINGER of Musée Océanographique de Monaco.

Five profiles will be discussed which are oriented normal to a line extending southwest from the Gulf of Genoa to the Balearic Islands. All profiles are reversed; four profiles are 80 km long while the fifth is 50 km long. Two profiles located in the deep water of the Western Mediterranean Basin show strong refraction arrivals from the base of the crust.

93. — *Dr. Popov* gives his paper : The dispersion of the long-period Love waves along the continental and oceanic paths from Indonesia to the Crimea.

The paper dwells on the Love surface waves with periods from 30 to 74 sec., recorded by a long-period horizontal seismograph at the Simferopol seismic station from an earthquake that occurred in the Molucca Sea on August 12, 1958. Observations revealed dispersion of the group velocity of L waves having travelled from Indonesia through the continent of Eurasia to the Crimea as well as of waves having travelled in the opposite direction from the focus through the anticentre and the Pacific and Atlantic Oceans.

The comparison of the experimental dispersion curves with theoretical ones showed agreement both for the continental (H = 40 km) and the joint continental and oceanic paths when considering the mean parameters of a homogeneous single-layer crust of the Earth. It is valid for the long-wave range.

Prof. Press remarks that 15 km is an unusually large thickness of an oceanic crust.

Mr. Dorman : The seismic refraction results for the continental path (Δ') generally indicate a somewhat greater crustal thickness than found from the one-layer Love-wave method. If a two-layered crust had been used, with the second layer having a velocity intermediate between that of the surface layer and that of the mantle, a greater crustal thickness would have been obtained by the Love-wave dispersion method.

94. — *Dr. Bott* presents his paper: Gravity anomalies over granites and their relation to the continental crust.

The evidence of negative gravity anomalies normally observed over granitic masses taken in conjuntion with density measurements on the rocks suggest that these intrusions usually extend downwards to about a third of the thickness of the continental crust. This observation demonstrates that the upper part of what is normally termed "the granitic layer" is significantly denser than either granite or granodiorite at about 2.75 g/cm^3, and is thus closer to diorite in average bulk composition. These results, combined with seismological evidence and geological considerations, combine to suggest a four-layered continental crust as follows :

0—10 km	sedimentary layer metasedimentary layer (dioritic composition)
10—30 km	? true granitic layer intermediate layer

The boundary between the granitic and metasedimentary layers is taken to represent the primitive crust before geological processes commenced. The model suggested is consistent with the idea of a thin crustal low-velocity layer corresponding to the granitic layer. It is thought that the layers may variably grade into each other.

The paper will be submitted for publication in the *Geophysical Journal*, of which a shortened version will appear in *Publications du Bureau Central Séismologique International, Sér. A, Trav. Sci., Fasc. No. 22*. Part of the substance presented has already been published earlier as follows :

1) *Geol. Mag.*, Vol. 90, 1953, pp. 257-267.

2) *Quart. J. Geol. Soc. Lond.*, Vol. 112, 1956, pp. 45-67.

3) *Bull. Geol. Soc. Amer.*, Vol. 66, 1955, pp. 1199-1202.

Mr. von Herzen : You mentioned some geologic evidence which may support the existence of a granitic layer in the crust underlying a metasedimentary layer. Could you discuss some of these ?

Dr. Bott : Two points come to mind in reply : 1) The abundance of Na in granites in relation to metasediments suggests a non-metasedimentary source for granite, at least in part. It is also difficult to explain the size of granite masses if these have originated by the differentiation of a basic magma. It seems to me that the simplest explanation to account for the origin of granites extending over 10 km is that a layer of granitic composition underlies the metasediments. — 2) Metasediments in bulk have a composition intermediate between granite and basalt. To account for this in time, it seems that the primitive crust of the continents must have contained granitic material overlying basaltic. Presumably some of this primitive granitic crust still underlies the metasedimentary layer.

The session is closed at 17.00.

18th SESSION

TUESDAY, AUGUST 2 (morning)

Program

1. — Scientific communications : Seismic Wave Propagation.

95. — *K. E. Bullen :* Seismic travel-times and velocity distributions.

96. — *N. F. Ness* and *J. C. Harrison :* Observations of the Earth's free modes at UCLA, using a La Coste-Romberg Earth-tide gravity meter.

97. — *B. A. Bolt :* Location of earthquake epicenters on the IBM 704 electronic computer.

98. — *I. M. Longman :* A new technique for the numerical solution of theoretical seismic problems.

99. — *J. Healy* and *F. Press :* Model seismology studies for media with variable density and velocity.

100. — *S. D. Kogan :* The travel times of the body waves for surface source.

101. — *A. M. Yepinatieva :* On the dynamic relation between the reflected and refracted waves.

102. — *I. P. Kosminskaya* and *R. M. Krakshina :* On supercritical reflections from the Mohorovičić discontinuity.

103. — *B. F. Howell, Jr. :* Absorption of seismic waves in rock.

104. — *C. Lomnitz* and *J. Ross Macdonald :* Théorie et applications de certaines fonctions linéaires d'atténuation.

The session is opened at 9.10 with *Prof. Byerly* as chairman.

1. — Scientific communications : Seismic Wave Propagation.

95. — *Prof. Bullen* presents his paper : Seismic travel-times and velocity distributions.

The author has previously shown that a law of the form $v = ar$ gives a useful first approximation to the seismic velocity distribution in various parts of the Earth. In the present paper, a method is presented of determining corrections to numerical values given by the law to fit a given set of seismic travel-time distance data.

The method provides an alternative to the classical Herglotz method of determining velocity distributions, and can be specially powerful in regions where the proportionate deviations from the above velocity law are small or moderate. The method is exact and the mathematical derivation has some features in common with the derivation of the classical procedure.

For purposes of illustration, the paper will give in outline the application of the method to the derivation of the P velocity distribution in the region E from the J.-B. tables.

If time permits, certain other applications of the law $v = ar^c$ will be presented, including consideration of discontinuities of the first or second order such as may occur in the outer mantle.

The paper will appear in *Publications du Bureau Central Séismologique International, Sér. A, Trav. Sci., Fasc. No. 21.* See also the *Geophysical Journal,* Vol. 3, No. 2, 1960, pp. 258-269.

Prof. Press : Do you mean to say that Gutenberg's inference of low-velocity layers, based on amplitude measurements, was not justified ?

Prof. Bullen : Yes.

Prof. Slichter : Would the decrease in velocity associated with Gutenberg's low-velocity layer in the upper crust be sufficient to cause violation of the conditions imposed by your theory ?

Prof. Bullen : My theory is intended primarily to apply to an Earth stripped of the crustal layers. An extension of the theory (to be published in 1961) does, however, deal with the case of a sudden decrease in velocity. At this stage, I think that the theory can be readily adapted to provide useful quantitative detail in cases such as a crust containing Gutenberg's low-velocity layer. I hope that later publications will cover this point.

96. — *Dr. Harrison* presents the paper by *N. F. Ness* and *J. C. Harrison :* Observations of the Earth's free modes at UCLA, using a La Coste-Romberg Earth-tide gravity meter.

The Institute of Geophysics (Los Angeles, California) has been engaged for some time in a program of research on the solid Earth tides. Significant improvements in the reading sensitivity and automatic recording of the data, obtained with a La Coste-Romberg tidal gravimeter, have recently been made. The present system allows automatic punching on paper tape of data read with a sensitivity of 0.1 μgal at 1, 5, 15 or 30-minute-intervals.

During the recent earthquakes in Chile the gravimeter was sampled for a 4.6-day period at 1-minute intervals. This period, from 0132 May 23 (GMT) to 1529 May 27, 1960, followed shortly after one of the large quakes. The hope in making such detailed measurements was to detect the free modes of oscillation of the Earth as excited by the earthquake.

Recently much attention has been devoted to the investigation of the free modes both theoretically and by analysis of observational data. Previous analyses of gravimeter data were unsuccessful in detecting these oscillations. It appears now that the increased sensitivity of gravity data recording, the more rapid sampling rate and the great seismic activity in Chile have combined to present the most unique gravity data yet obtained.

The methods of analysis applied have included the standard power spectrum techniques developed in statistical communication theory. While this method is very powerful for revealing spectral peaks, it does not allow the resolution of detail frequency spectrum structure which is necessary in a study of the Earth's free modes. In conjunction with the standard earth-tide gravity analyses, frequency analysis techniques that yield maximum resolution of the frequency spectrum for a given set of data have been developed. These techniques employ special Chebyshev "time" windows which yield maximum resolution and minimum contamination of spectral estimates.

A primary problem in the observation of the free oscillations, by means of the gravimeter, is their small amplitude relative to the 12 and 24-hour earth tides. For a significant and meaningful analysis of the gravity data, the earth tides must be subtracted from the raw gravity data. This was accomplished by the use of specially constructed numerical Chebyshev high-pass filters. These successfully eliminated the major portion of the low-frequency energy associated with the earth tides.

A detailed resolution of the peaks revealed by the power spectrum analysis has revealed new features. In particular, the fine structure of the frequency spectrum at the 35.5-minute period of the 3rd mode fundamental spheroidal frequency shows splitting of this mode into two components, one with a period of 35.9 minutes and the other with a period of 35.2 minutes. This is due to the rotation and ellipticity of the Earth. Splitting of the 53.7-minute period into 53.0 and 54.8-minute periods is also found. Comparison of the observed frequencies with theoretical results has yielded very close agreement. The radial fundamental mode is found with a period of 20.5 minutes, and predicted at 20.8 minutes. Preliminary comparisons favor Bullen's Model B for the preferred Earth model.

The program of earth-tide gravity research at the Institute of Geophysics of the University of California is under the general direction of Professor L. B. Slichter. The full cooperation of the Western Data Processing Center of UCLA, in providing the computational facilities of the IBM 709, is gratefully appreciated.

The paper has been published in the *Journal of Geophysical Research,* Vol. 66, no. 2, 1961, pp. 621-629 (together with *L. B. Slichter*).

Prof. Slichter refers to the agreement found with other data (by Benioff and Press), reported in an earlier discussion (5th Session, paper 10).

Prof. Tsuboi asks if data on the Chile earthquakes will be collected on a world-wide basis.

Prof. Slichter says in reply that this was the only gravimeter which had sufficient quality to record very long waves. Only very few instruments could record such long waves.

97. — *Dr. Oliver* reads the paper by *B. A. Bolt* : Location of earthquake epicenters on the IBM 704 electronic computer.

A program has been designed for the IBM 704 electronic computer which revises preliminary epicenters and origin-times of earthquakes.

The method follows that of Jeffreys and Bullen ; from observed travel-times of P and PKP seismic waves, equations of condition of the form

$$T - (x\sin\alpha + y\cos\alpha)\frac{\delta t}{\delta \triangle} + z\frac{\delta t}{\delta z} = \mu$$

are solved for $T, x, y,$ and z by least squares (x and y are east and north corrections to the preliminary epicentre, $6338z$ is the increase of the focal depth, and T the increase required in the origin-time.)

Residuals (μ) are formed using the Jeffreys-Bullen tables which are stored in a complete form in the computer. Weights are allotted to each equation according to the difference between the particular residual and the average residual in the corresponding quadrant. Solution of the normal equations is by Gaussian elimination using the largest coefficient in the first column as pivot.

Any number of earthquakes, each with up to 300 P and PKP observations, can be treated at one time. Computation time is about 3 mn per earthquake. The printed output includes a list of stations involved together with their distances and azimuths, calculated from the final epicentral solution, and the corresponding travel-time residuals.

The paper has been published under the title "The revision of earthquake epicenters, focal depths and origin-times using a high-speed computer" in the *Geophysical Journal,* Vol. 3, No. 4, 1960, pp. 433-440.

Dr. Oliver answers in the affirmative both to a question by *Dr. Ritsema* if compressions and dilatations can be included, and to a question by *Dr. Lapwood* if the machine rejects observations which deviate strongly.

98. — *Dr. Longman* gives his paper : A new technique for the numerical solution of theoretical seismic problems.

The theoretical analysis of problems in seismology leads in many cases to solutions expressed in terms of integrals which cannot be evaluated by conventional numerical methods. The usual difficulties are connected with the oscillatory nature of the integrand and with the presence of one or more poles on the path of integration. In the simpler problems these difficulties can sometimes be circumvented by appropriate transformations in the complex plane, though this often involves lengthy analysis.

This paper presents a method which has been developed by the author for the direct and accurate evaluation of such solutions with a minimal use of algebra. The power and simplicity of the method is illustrated by applying it to the solution of important problems.

The paper has appeared in the *Journal of Geophysical Research* under the title "A technique for the numerical solution of geophysical problems", Vol. 65, No. 11, 1960, pp. 3795-3800.

Father Ingram : Can your method be readily applied to the problem of finding the displacements in an elastic medium when arbitrary stresses are suddenly applied to a small sphere surrounding a point of the medium ?

Dr. Longman : Yes. The method can be applied to all these problems, where the solution can be expressed in integral form.

Dr. Lapwood : Are the small oscillations of amplitude shown on the graph part of the solution, or do they represent inaccuracies due to the use of Euler's transformation? Is the precision of the solution within the accuracy of the drawing of the curves ?

Dr. Longman : The small oscillations are real. The accuracy of the numerical results is far higher than the accuracy of the drawing of the curves.

Prof. Press : Can this method be applied to dispersive propagation in layered media ?

Dr. Longman : Yes. All these problems can be solved with facility. Any solution which can be expressed as a single or double integral even if infinite and/or having singularities on the path of integration can be readily evaluated.

99. — *Prof. Press* presents the paper by *J. Healy* and *F. Press :* Model seismology studies for media with variable density and velocity.

A method for fabricating two-dimensional ultrasonic models with variable velocity and density is described. The method is justified theoretically and experimentally. It is tested by comparing the experimental and theoretical dispersion of Rayleigh waves in a model of two-layered earth crust. Several methods of deducing the dispersion in a train of surface waves are compared :

1) Brune's method,

2) Press' method,

3) The method of free vibrations,

4) Fourier analysis of digitized seismograms.

All methods are satisfactory but the last method alone is sufficiently accurate to reveal fine structure in the dispersion curve.

The paper has been published in *Geophysics,* Vol. 25, No. 5, 1960, pp. 987-997.

Mr. Lavergne : When making amplitude measurements from seismograms obtained on two-dimensional models, is it always possible to take into account the fact that the attenuation of amplitude is not the same in a two-dimensional medium as in a three-dimensional medium ?

Prof. Press : In most cases a simple correction predicted by theory can be used.

Mr. J.K. Wright : We are using this double-layer technique to study the effect of the low-velocity channel in the upper mantle on the amplitude of body waves. One difficulty we have encountered is the need to obtain a really good bond between the two materials. Would you like to elaborate on this practical point ?

Prof. Press : The metal surface must be scrupulously clean. Firm bonds were obtained by using resin plastic.

100. — *Prof. Riznichenko* reads the paper by *S. D. Kogan :* The travel times of the body waves for surface source.

The seismic records of nuclear explosions conducted by the U.S.A. in the region of Marshall Islands have been used to determine the actual travel time of the seismic waves within a great interval of the epicentral distances and also to compare them with the data of the Jeffreys-Bullen tables.

On the basis of 232 arrivals of the P-wave at 69 stations of the world have been fixed that deviation δt_p of the actual travel time of this wave from the Jeffreys-Bullen tables depends neither on azimuth nor on epicentral distance. The average value $\delta t_p = 1.8 \pm 0.6$ sec. Consequently the experimental P time-curve for surface source in the western part of the Pacific Ocean reduced to the standard sphere within the interval of epicentral distances from 30° to 104° is parallel to the Jeffreys-Bullen time-curve but is lower than the latter by 2 sec. The result coincides with Gutenberg's and Bullen's data who explain the decrease of P-wave travel time by the small thickness of the granite layer in the region of epicenter. Such explanation is confirmed by the observations at seismic stations situated on Pacific islands and by the data of PP-waves whose travel times are less than by the Jeffreys-Bullen tables by about 5 sec. The travel time of PcP-wave within the interval of epicentral distances 40°-80° is less than by the tables by about 3 sec. One of the possible explanations of the difference between δtPcP and δt_p may be some greater radius of the Earth's core (3486 km) than it was accepted (3473 km) by calculation of Jeffreys-Bullen table of PcP-wave.

For the transverse waves S and SKS in contradistinction to longitudinal ones the travel time is by 4-5 sec greater than the corresponding values according to the tables. The absence of marked change in δt_s with epicentral distance permits to suppose that the transverse wave velocity for the upper part of the mantle should be actually less than the accepted values.

The fact that by explosions near the Earth's surface considered here besides compressional waves also transverse waves are registered, for which the component SV is substantially greater than the component SH permits to consider the explosions of such type as vertical shocks.

The paper is published as follows :

1) In Russian in *Izv. Acad. Sci. USSR, Ser. Geofiz.,* No. 3, 1960, pp. 371-380.
2) In English in *Publications du Bureau Central Séismologique International, Sér. A, Trav. Sci., Fasc. No. 21.*

Prof. Byerly wonders if the slow S waves found could be due to a soft layer below the crust.

Dr. Oliver : Carder and Bailey observed extreme variations of the amplitudes of PcP over certain small distance ranges (*Bull. Seism. Soc. Amer.,* Vol. 48, No. 4, 1958, pp. 377-398). Have you observed similar effects ?

Prof. Riznichenko, in reply : I have presented here the kinematic part of Kogan's study. The author gives some remarks about the amplitudes and dynamics in her manuscript. But the author is not present here and unfortunately I cannot give any explanations to the dynamic part of Kogan's study.

Prof. Press : The delay in S indicates slightly lower shear wave velocities in the upper mantle, as the author points out. This is important in delineating the low-velocity layer by mantle Rayleigh-wave dispersion and actually permits a better fit to experiment than could be obtained before.

101. — *Prof. Karus* presents the paper by *A. M. Yepinatieva :* On the dynamic relation between the reflected and refracted waves.

1. The relation between the reflected and refracted (head) wave intensities (corresponding to one and the same boundary and registered at the angles of incidence greater than critical) differs depending on different media and on different distances from the initial points. The cases have been noticed during experiments when the intensity of the reflected waves had been greater or about equal or less than that of the refracted waves. The experimental study of waves in the real media and theoretical calculations show that the relation between the reflected and refracted wave intensities depends on the absorbing properties of the media, on values of the velocities, on the distance and on the frequency of the oscillations. In the absorbing medium the decrease of the reflected wave's intensity in comparison with that of the refracted wave takes place with the distance (beginning from a certain one). According to the experimental data beginning from some distance the reflected wave ceases to be outlined on the seismogram but the refracted wave could be correlated at great intervals of distance.

2. At the little relative intensity of the refracted wave the reflected wave while passing the critical angle is correlated continuously without marked changes of record form while the amplitude is gradually decreasing with the distance. When the refracted wave is more intensive than the reflected one, then while passing the critical angle sharp changes of the record form and of the intensity of summary oscillation are frequently noticed which are connected with the appearance of the refracted wave.

3. The study of the reflected and refracted wave dynamics beyond the initial point is important for the study of problems of wave propagation physics and also for the development of the criteria for the recognition of the waves registered on the subsequent part of the seismogram while conducting the works by correlation refraction method, deep seismic sounding and in seismology.

The paper will appear in *Publications du Bureau Central Séismologique International, Sér. A, Trav. Sci., Fasc. No. 21.*

Prof. Press asks if the location of the measurements was chosen so as to obtain simple and clear records.

Prof. Karus, in reply : Yes, but more complicated regions are now also under investigation.

102. — *Mrs. Dr. Kosminskaya* presents the paper by *I. P. Kosminskaya* and *R. M. Krakshina :* On supercritical reflections from the Mohorovičić discontinuity.

Supercritical reflections are reflected waves followed along distances greater than those corresponding to the initial points of time-distance curves for refracted waves.

Supercritical reflections from the Mohorovičić layer were picked out from seismograms obtained by deep seismic sounding carried out, according to the IGY program, in the zone of transition from the Asiatic continent to the Pacific Ocean.

The main criteria used in identifying the supercritical reflections were : a decrease in their apparent velocity with distance from the shooting point ; non-parallelism of the overlapping time-distance curves and their considerable intensity.

Supercritical reflections are observed locally. They were most clearly recorded in the central part of the Okhotsk Sea, having a continental crustal structure and a thick enough granite layer. In the deep-water part of the Okhotsk Sea, where the crustal structure is of an intermediate type, no supercritical reflections were recorded. In the ocean, supercritical reflections were recorded in very small sections only.

The supercritical reflections are distinguished by their clear appearance on the records ; by an intensity surpassing that of all other waves, and by a damping sharply increasing.

A comparison between simultaneously recorded refracted waves and supercritical reflections has shown that the intensity of the latter is about 3-4 times that of the former. The observed frequencies of the refracted waves were higher than the prevailing frequencies of the supercritical reflections.

The time-distance curves of the supercritical reflections were used for the determination of the mean velocity in the crust and of the depth of the Mohorovičić discontinuity.

The paper will appear in *Publications du Bureau Central Séismologique International, Sér. A, Trav. Sci., Fasc. No. 21.*

Mrs. Dr. Kosminskaya, in reply to a question from the audience, says that no S waves were studied, only P waves.

103. — *Prof. Howell, Jr.,* presents his paper : Absorption of seismic waves in rock.

Attenuations of seismic waves in the ground were measured using a transient (impact) source and a continuous-wave (vibrator) source. Attenuation as a function of distance was determined for frequencies in the range 40-160 cps. The spectra of the transient pulses were determined by Fourier analysis. In the case of the transient pulses, assuming annular divergence with attenuation of the energy proportional to (distance)$^{1/2}$, the data can be described best by an exponential absorption of coefficient $\alpha = 4.9 \times 10^{-7} f^2$, where f is frequency in cycles per second. In the case of the continuous waves, again assuming an annular divergence of the energy with attenuation proportional to (distance)$^{1/2}$, the best value of the absorption coefficient is $\alpha = 0.00096 f^{0.9}$. Although the values of absorption obtained by the two methods appear to be inconsistent, considering the differences in the nature of the waves and the scatter of the data, the difference may be explainable. Under certain circumstances (in the presence of layering) an annular divergence proportional to the first power of distance or (distance)$^{5/6}$ is expectable for a transient pulse. Allowance for such a difference in annular-divergence rates of transient as compared to continuous waves brings the data into closer but not complete agreement.

The paper will appear in *Publications du Bureau Séismologique International, Sér. A, Trav. Sci., Fasc. No. 21.* Other papers by Prof. Howell on related subjects have appeared in *Bull. Seism. Soc. Amer.*, Vol. 39, 1949, pp. 285-310, and Vol. 44, 1954, pp. 481-491 (with E. K. Kaukonen), *Geophysics*, Vol. 20, 1955, pp. 33-52 (with D. Budenstein), *Earthquake Notes*, Vol. 17, 1956, pp. 23-26 (with S. P. Mathur), and Vol. 28, 1957, pp. 21-28, *Publ. Bur. Centr. Séism. Int., Trav. Sci.*, A: 20, pp. 55-66.

Mr. Hjelme asks on which medium the measurements were made.

Prof. Howell : The formations were a series of Devonian sediments, nearly horizontal, exposed in the floor of a strip mine. These are layered at short intervals (several feet thickness), which is far from ideal for such experiments and contributes to the complexity of the pulses even at short distances.

Prof. Nafe : Can you tell us the degree of water saturation of the rocks on which your measurements were made ? This will probably influence the frequency dependence of attenuation.

Prof. Howell : The rocks were exposed in the bottom of two strip mines. Both mines were near the summits of hills with the water table at an unknown depth. I believe the rocks to be partially water saturated by descending surface waters. The experiments were carried out in a strip mine to obtain relatively unweathered, firm rock.

104. — *Prof. Lomnitz* gives the paper by *C. Lomnitz* and *J. Ross Macdonald :* Théorie et applications de certaines fonctions linéaires d'atténuation.

H. Jeffreys a démontré que l'on peut expliquer une grande variété de données expérimentales de fluence et d'atténuation des ondes au moyen de l'équation générale suivante :

$$\phi (t) = (q/v) [(1 + t/\tau o)^{v} - 1]$$

qui se réduit à la régle logarithmique pour $v \rightarrow o$. Bien que cette fonction de fluence aboutisse à une vitesse de déformation initiale finie, elle implique une déformation finale infinie ; donc elle représente un système linéaire non réalisable du point de vue physique.

On propose une modification simple de la fonction de distribution des temps de relaxation qui, sans changer la forme de la fonction la ferait converger pour un temps de l'ordre de l'âge de la terre.

On dérive les fonctions d'atténuation en terme de fonctions de Lommel, et on donne des graphiques de Q (ω). On démontre que la fonction proposée s'accorde avec les données d'atténuation dans la croûte et le manteau supérieur entre les périodes d'une seconde à

430 jours, ainsi qu'avec les données sur l'accélération séculaire de la lune, de Mercure et des satellites de Mars, avec le soulèvement de la Fennoscandie, et les données sur la fluence des solides polycrystallins. On discute aussi les sujets de l'isostasie, les courants de convection et les séquences de répliques.

A paper on a related subject by J. Ross Macdonald has appeared in the *Geophysical Journal,* Vol. 2, No. 2, 1959, pp. 132-135.

The session is closed at 12.20.

19th SESSION

TUESDAY, AUGUST 2 (afternoon)

Program

1. — Scientific communications : Seismic Wave Propagation ; cont.

105. — *K. Wadati :* On the T-phases observed at Torishima.

106. — *E. Peterschmitt :* Ondes Lg et séismes proches.

107. — *N. G. Waldner* and *E. F. Savarensky :* Observations of Lg and Rg waves.

108. — *M. Båth :* Channel waves or higher-mode surface waves ?

109. — *I. S. Berzon :* The methods and some results of the interpretation of seismic waves spectral analysis data.

110. — *E. R. Lapwood :* Transmission of a Rayleigh pulse round a corner.

111. — *Z. Alterman, H. Jarosch,* and *C. L. Pekeris :* Dispersion of Rayleigh waves in the Earth.

112. — *L. Knopoff :* The inversion of surface wave dispersion data.

113. — *C. H. Dix :* Simplified theory of the conical refracted pulse.

114. — *M. Lavergne :* Recherches expérimentales sur modèles sismiques ; problèmes de diffraction et de réfraction.

Election of members of COSPAR.

The session is opened at 14.30 under the chairmanship of *Sir Harold Jeffreys.*

1. — Scientific communications : Seismic Wave Propagation (cont.).

105. — *Prof. Wadati* gives his paper : On the T-phases observed at Torishima.

Torishima (30°29'N, 140°18'E) is an isolated island in the Pacific Ocean to the south of Japan, and is surrounded by deep seas. Accordingly, the seismological station situated on this island is favored with good conditions for observing the T-phases in seismic waves.

The author has investigated the records of seismological observations at the said station for the four years from 1954 to 1957, and has found 42 seismograms which register conspicuous T-phases. The position of epicenter and the depth of focus of these earthquakes which gave these T-phases have been searched for, and investigation has been made on the problem, at what sort of place the earthquake had occurred, when T-phases were observed.

It is a well-known fact nowadays that the T-phases are the seismic waves which first are transformed into sound waves in the sea water and then again become seismic waves to be observed by seismographs. The author has ascertained this fact by obtaining the travel times of T-phases for the respective cases from the observations at Torishima. The following results are here obtained.

1) Earthquakes having their epicenters inland, also, give T-phases.
2) The depth of focus of the earthquakes which gave T-phases are predominantly distributed in a range of 100-200 km.
3) In this investigation there are not found any deep earthquakes with their foci more than 300 km deep which gave T-phases.
4) Some of the T-phases belong to the reflected waves which are produced by the reflection of sound waves propagating in the sea water and reach the observing station.
5) T-waves are rapid oscillations, but their attenuation is little, compared with that of ordinary seismic waves, and they reach large distances beyond expectation, so that in some cases the seismograph records no ordinary seismic waves but T-phases only.

The investigation which seems most interesting in the present paper is that on the T-phases caused by an underwater explosion test of the atomic bomb in the sea off California on May 14, 1955. It is reported that, from this explosion, seismographs on the islands and coasts of Japan observed T-phases only and at some places the shocks were felt on human body with the intensities of II or III. Ordinary earthquakes hitherto have never given to human body such sensation at so large a distance as 8.000 km from the seismic origin.

With reference to the investigations on this explosion by Oliver and Ewing (*Trans. Amer. Geophys. Union,* Vol. 39, No. 3, 1958, pp. 482-485) and by Sheehy and Halley (*Journal Acoust. Soc. Amer.,* Vol. 29, 1957, pp. 464-469) the author has given his interpretation of the complicated T-phase groups which this explosion gave on the seismograms at Torishima.

The paper has been published in the *Geophysical Magazine,* Japan Meteorological Agency, Tokyo, Vol. 30, No. 1, 1960, pp. 1-18.

Capt. Grinda demande si le Prof. Wadati connaît la topographie du fond de la mer autour d'épicentres des séismes ayant donné naissance à des ondes T.

Prof. Wadati : The detailed mechanism of transformation from seismic waves to sound waves in the water at the sea bottom will be postponed until a later investigation.

106. — *Mr. Peterschmitt* reads his paper : Ondes Lg et séismes proches.

La répartition des vitesses des trois ondes principales Li (v = 3,80) Lg_1 (v = 3,55), Lg_2 (v = 3,35) montre que ces ondes doivent être considérées comme la continuation à plus grandes distances des ondes transversales principales des séismes proches Sb, Sgr (r = rapide) et Sgl (l = lent). Les ondes longitudinales correspondantes se propagent avec des vitesses voisines de 6,5, 6,0 et 5,7 km/sec.

Discussion des diverses hypothèses possibles (ondes canalisées, ondes guidées, ondes transversales...).

Dr. Båth : In agreement with Mr. Peterschmitt I have found already earlier, that there is a complete continuity from the near-earthquake phases to the channel waves, observed at greater distances. See e.g. *Gerlands Beiträge zur Geophysik,* Bd 68, H. 6, 1959, pp. 360-376.

107. — *Dr. Soloviev* reads the paper by *N. G. Waldner* and *E. F. Savarensky :* Observations of Lg and Rg waves.

Some data on the damping of Lg and Rg waves propagating through the central part of the Black Sea Region have been found.

They are based on the study of the seismograms of the Moscow Seismological Station and others with records of over 70 earthquakes in Greece, Turkey and South Europe. This fact is in accordance with the results of seismic sounding of the Earth's crust to the south from the Crimean Peninsula, concerning the absence of granitic layer in the deep-water zone of the Black Sea.

Some peculiarities of the Lg, Rg waves have been found out on the model discussing the results of the experiment.

Some ideas concern the influence of the mechanism of foci.

The paper has been published in *Annali di Geofisica,* Vol. 13, No. 2, 1960, pp. 129-134, and Vol. 14, No. 1, 1961, pp. 95-102.

108. — *Dr. Båth* gives his paper : Channel waves or higher-mode surface waves ?

Lg1, Lg2, and related waves have alternatively been interpreted as channel waves in the continental crust and as higher-mode surface waves. A series of observations are mentioned, which must be explained by any theory for these waves, before it can be definitely accepted : dispersion properties ; character of the onset, if sharp or gradual ; observed velocities, compared with results from near earthquake and explosion records ; velocity independent of period ; possibility to record the wave on the earth's surface ; the existence and rôle of low-velocity layers ; observations of longitudinal channel waves in the crust ; observations of Pa, in addition to Sa.

In conclusion, we note that there seem to be reasons for the existence both of channel waves and of higher-mode surface waves. A more thorough theoretical and observational knowledge is needed in both cases, before a judgment can be made. Until the problems outlined above are satisfactorily answered, we leave the explanation as an open problem.

The paper presented has appeared as chapter 6 in a more extensive paper, published in *Gerlands Beiträge zur Geophysik,* Bd 68, H. 6, 1959, pp. 360-376.

109. — *Prof. Karus* reads the paper by *I. S. Berzon :* The methods and some results of the interpretation of seismic waves spectral analysis data.

1. The methods of spectral analysis of seismic waves are now used in seismology and seismic prospecting, mostly to choose optimum conditions for wave recording. Apart from that, the data of the wave spectral analysis can be utilized to determine new parameters of the medium : absorption coefficients and coefficients of reflection from thin layers.

2. Methods of processing the spectra of reflected and refracted (head) waves of different types are suggested. The methods are based on the joint processing of the spectra of two or three waves corresponding to different discontinuities. The waves involved must be recorded for the same explosion (or earthquake) in one and the same point. In this case the spectrum of the explosion (or the earthquake) and spectral characteristics of the seismograph are not considered.

3. The methods suggested determine the dependence on the frequency of coefficients of reflection of P waves from thin layers and absorption coefficients of P and S waves along the refracting boundaries, and in media covering reflecting and refracting boundaries.

4. The results of determining the dependence on the frequency of the wave absorption coefficients and of coefficients of reflection from thin layers are given. The results are obtained by experimental investigations in real stratified media with explosions.

The dependence of the absorption coefficients of P waves on the frequency is often found to approach the linear, a more complex dependence on the frequency being occasionally observed. The graphs of the dependence of the wave reflection coefficient on thin layers have mostly a sharp resonance form.

5. The suggested methods of processing the spectral analysis data are applicable in the seismic prospecting, in the modelling of seismic wave processes, in the seismic depth sounding and seismology. The study of the frequency dependence of the absorption coefficients and reflection coefficients of seismic waves is of significant value for the further development of seismic methods of investigation.

The complete paper will appear in *Publications du Bureau Central Séismologique International, Sér. A, Trav. Sci., Fasc. No. 21.*

110. — *Dr. Lapwood* gives his paper : Transmission of a Rayleigh pulse round a corner.

Lamb, in his classical paper of 1904, found the form of the Rayleigh pulse that travels over the surface of an elastic half-space, when it has been struck along a line. Let such a pulse travel on one face of an elastic quarter-space, the crest-line being parallel to and travelling towards the edge. We enquire what form the Rayleigh pulse will have after passing round the corner.

The problem is taken as two-dimensional ; the elastic solid fills the positive quadrant xOy, and the incident Rayleigh pulse arises from a pressure

$$p\ (x,\ t) = -\ Q\ \delta\ (x\text{-}a)\ \Phi\ (t)$$

applied on the face $y = O$.

The differential equations and boundary conditions are reduced to operational form by the use of Fourier transform w.r.t. time and Laplace transforms w.r.t. x and y. Difficulties arise from our lack of knowledge of the displacements at the surfaces $x=O$ and $y=O$, but solution of the problem is reduced to that of two simultaneous integral equations.

An iterative solution can be found, and from this we isolate the parts which describe the incident Rayleigh pulse (identical with Lamb's solution) and the pulse transmitted round the corner.

It is found that the form of the pulse is greatly changed, in ways depending on the values of the velocities of P, S, and Rayleigh waves. Whereas the displacements u and v on $y=O$ have the shape of $\Phi\ (t)$ and its *allied function* (Hilbert transform) $\Phi'\ (t)$ respectively, each of u and v on $x=O$ is given by a linear combination of Φ and Φ'. Since Φ' may differ greatly from Φ in form, the change in shape of each component of displacement when it turns the corner may be very marked.

The paper will be published in the *Geophysical Journal*, Vol. 4, 1961 ("Special Harold Jeffreys Volume").

111. — *Prof. Pekeris* presents the paper by *Z. Alterman, H. Jarosch*, and *C. L. Pekeris* : Dispersion of Rayleigh waves in the Earth.

Previous calculations of the periods T of free oscillations of the Earth have been extended to higher orders of the spherical harmonics n, for the purpose of determining the phase velocity C and the group velocity U of Rayleigh waves in the spherical Earth. The Rayleigh wave dispersion curves $C\ (T)$ and $U\ (T)$ for Bullen's model B will be presented.

The paper will be published in the *Geophysical Journal*, Vol. 4, 1961 ("Special Harold Jeffreys Volume").

The chairmanship is handed over to *Prof. Slichter*.

112. — *Prof. Knopoff* gives his paper : The inversion of surface wave dispersion data.

Perturbation theory has been applied to the problem of the determination of the structure that gives rise to a given observation of surface wave velocity as a function of frequency. The procedure is a form of the Born approximation and is therefore valid for wave lengths long compared with the spatial rate of change of the properties of the structure. A theory already exists for the short wave length approximation. The perturbation procedure is well suited to the determination of abrupt discontinuities in structure.

The calculation starts with the solution for the eigenvalues of a certain initially assumed structure. A perturbing layer of infinitesimal thickness and arbitrary physical properties is then introduced at an arbitrary depth. The perturbation in the eigenvalue equation is then determined; a Green's function for the eigenvalue problem thus has been found. An integral equation may be written that determines the physical properties of the perturbation of the initial structure, corresponding to a difference between the dispersion curves observed and calculated for the initial assumption. A theorem may be written that states that no uniqueness exists : a unique distribution of density and elastic constants does not exist for a given dispersion curve.

The inversion of the integral equation has been successfully accomplished for Love waves using an initial assumption of a homogeneous layer over a homogeneous half-space. The result is expressed as an inverse cosine transform in the layer and as an inverse Laplace transform in the half-space; the arguments of the inverse transforms are the observed perturbations in the dispersion curves and certain weighting functions derived from the solution to the eigenvalue problem for the initially assumed structure.

The paper will appear in the *Geophysical Journal,* Vol. 4, 1961 ("Special Harold Jeffreys Volume") under the title : Green's function for eigenvalue problems and the inversion of Love wave dispersion data.

113. — *Prof. Dix* presents his paper : Simplified theory of the conical refracted pulse.

The conical pulse is given in a form derived from Cagniard (Réflexion et Réfraction des Ondes Séismiques Progressives, Paris 1939) by some modifications making the theory simpler and numerical computation easy. For an input step irrotational potential the vertical displacement is a step function multiplied by a series of functions of simple form representing successive approximations. For many purposes the first approximation is sufficient. There are several conical pulses possible, each of which can be treated in the same simple way. The implications regarding design of instruments for detection of conical pulses are discussed.

The material presented is published as follows :

1) The seismic head pulse, *Geophysics* (in press).

2) The reflected seismic pulse, *Journal of Geophysical Research*, Vol. 66, No. 1, 1961, pp. 227-233.

3) Elastic pulse reflection. Evaluation of some determinants, *Journal of Geophysical Research*, Vol. 66, No. 1, 1961, pp. 235-236.

See also *Publications du Bureau Central Séismologique International*, Sér. A, Trav. Sci., Fasc. No. 21.

114. — *Mr. Lavergne* gives his paper : Recherches expérimentales sur modèles sismiques ; problèmes de diffraction et de réfraction.

La technique des modèles à ultrasons est appliquée à l'étude expérimentale de deux problèmes fondamentaux de la propagation des ondes sismiques.

— L'étude des diffractions créées dans un solide homogène par un écran semi-infini parfaitement réfléchissant permet d'observer les ondes de dilatation et de distorsion diffractées issues de l'extrémité de l'écran diffracteur. Diverses propriétés de la source de diffraction sont déterminées.

— Le problème de la détermination des couches minces par la sismique réfraction est étudié. Les vitesses de propagation de l'onde réfractée le long de la couche mince sont dispersives. Elles varient avec l'épaisseur de la couche suivant des lois qui sont déterminées.

The paper will appear in *Publications du Bureau Central Séismologique International*, Sér. A, Trav. Sci., Fasc. No. 21.

During the session the following delegates were elected as representatives of our Association in COSPAR : *Prof. Bullen, Prof. Ewing, Prof. Karus.*

The session is closed at 17.50.

20th SESSION

WEDNESDAY, AUGUST 3 (morning)

Program

1. — Scientific communications : Bodily Tides.

115. — *R. Tomaschek :* Presidential introduction.

116. — *P. Melchior :* Rapport sur les Marées Terrestres 1957-1960.

117. — Discussion of phenomena related to seismology.

118. — *L. B. Slichter* and *M. Caputo :* Deformation of an Earth model by surface pressures.

119. — Comparison of results from different stations.

This symposium is held together with IAG. Most of the material presented and discussions have appeared in *Bulletin d'Informations, Commission Permanente des Marées Terrestres,* Nos 20-22, edited by Dr. Melchior. Paper 116 appears in No. 20, and paper 118 in No. 22. Paper 118 has also been published in the *Journal of Geophysical Research,* Vol. 65, No. 12, 1960, pp. 4151-4156. A second session on Bodily Tides on Thursday, August 4 (morning), is also reported by Dr. Melchior.

21st SESSION

WEDNESDAY, AUGUST 3 (morning)

Program

1. — Scientific communications : Fault-Plane Work and Source Energy.

120. — *V. I. Keilis-Borok, V. M. Naymark,* and *I. I. Tshetshel :* Investigations of the earthquake mechanism.

121. — *L. M. Balakina, H. I. Shirokova,* and *A. V. Vvedenskaya :* Studying stresses and ruptures in the earthquake foci with help of dislocation theory.

122. — *P. Byerly :* The transformation of elastic strain energy into kinetic wave energy at the source of an earthquake.

123. — *L. Knopoff :* The statistical accuracy of the fault-plane method.

124. — *W. Stauder, S. J. :* S waves and focal mechanisms.

125. — *H. Honda :* Generation of the seismic waves.

126. — *K. Aki :* The use of long-period surface waves for the study of earthquake mechanism.

127. — *J. Brune, J. Nafe,* and *J. Oliver :* Phase analysis of surface waves to determine initial phases at the origin.

128. — *N. Öcal :* Die Bestimmung des Mechanismus mit der Methode von Byerly-Hodgson bei einigen Erdbeben in Nord- und West-Anatolien.

129. — *T. I. Kukhtikova :* Dislocations in foci of the Tadjik depression.

130. — *A. E. Scheidegger :* The tectonics of Asia in the light of earthquake fault-plane solutions.

131. — *G. J. Lensen :* Principal horizontal stress directions as an aid in the study of crustal deformation.

132. — *A. R. Ritsema :* Further focal mechanism studies at De Bilt.

133. — *R. E. Ingram, S. J. :* Generalized focal mechanism.

The symposium is opened at 9.00 under the chairmanship of *Dr. Hodgson.* Unless otherwise mentioned, the complete papers presented in this symposium will appear in the *Publications of the Dominion Observatory, Ottawa,* Vol. 24, No. 10.

1. — Scientific communications : Fault-Plane Work and Source Energy.

120. — *Dr. Hodgson* gives a brief presentation of the paper by *V. I. Keilis-Borok, V. M. Naymark,* and *I. I. Tshetshel :* Investigations of the earthquake mechanism.

The diffraction of waves on the edge of the fault-plane and the possible boundaries near it affect strongly the mathematical model of the earthquake source. The influence of both these factors on the nodal lines of the longitudinal and the transverse waves is investigated.

121. — *Mrs. Dr. Vvedenskaya* reads the paper by *L. M. Balakina, H. I Shirokova,* and *A. V. Vvedenskaya :* Studying stresses and ruptures in the earthquake foci with help of dislocation theory.

According to the modern ideas about nature of seismic phenomena the earthquake mechanism is connected with the ruptures of the continuity of the medium in the focus. It can be supposed that rupture accompanied by a slip in the conditions of considerable hydrostatic pressure is the most probable form of displacement in earthquake foci.

The limited area of the rupture of the continuity of an elastic medium, whose opposite faces move one relative to the other in the glide plane is considered as the most probable theoretical model of an earthquake focus.

Force model of this source is established on the basis of dislocation theory and the field of the displacements of the longitudinal and transverse waves are determined.

The predominant directions of the principal stresses in the foci of earthquakes in the North-West Pacific, in the Hindu-Kush, in the near Baikal region and Mongolia are determined with help of such model of earthquake focus, on the basis of the observations on the amplitudes of the longitudinal and transverse waves.

The investigation of the earthquake foci in the north-western part of the Pacific Ocean showed that in the overwhelming majority of cases the pressure has a greater horizontal than vertical component, orientated approximately at right angle to the orogenic axis. The tension has the vertical component greater or equal to the horizontal one.

Movements in foci are of various character which does not indicate predominance of shear components.

The region of the Hindu-Kush earthquakes is characterized by movements of the type of a thrust with very small components in the direction of the strike.

The pressure is almost horizontal and orientated approximately perpendicular to the strike of the structures, just as tension is directed almost vertically.

The predominant directions of the axes of the principal stresses in the foci of the earthquakes in the near Baikal region and in Mongolia were not found.

In addition to the publication from the Dominion Observatory, Ottawa, this paper has been published in parts in Russian as follows :

1) Vvedenskaya A. V. : On determination of stresses acting in earthquake sources from observation of seismic stations, *Izvestiya AN SSSR, Ser. Geophys.*, N4, 1960, pp. 513-519.

2) Vvedenskaya A. V. : On determination of displacement fields by means of dislocation theory, *Izvestiya AN SSSR, Ser. Geophys.*, N3, 1956, pp. 277-284.

3) Vvedenskaya A. V. : On displacement fields for the ruptures of the continuity of elastic medium, *Izvestiya AN SSSR, Ser. Geophys.*, N4, 1959, pp. 516-526.

4) Shirokova H. I. : Determination of stresses acting in foci of Hindu-Kush earthquakes, *Izvestiya AN SSSR, Ser. Geophys.*, N12, 1959, pp. 1739-1744.

5) Balakina L. M. : On distribution of stresses acting in earthquake foci of the north-western part of the Pacific, *Izvestiya AN SSSR, Ser. Geophys.*, N11, 1959, pp. 1599-1604.

Father Ingram : I would like to note that the forces shown are the stresses before and after an earthquake. I would like to ask if this system is the same as that considered by Prof. Beloussov in his discussion on Island Arcs.

Mrs. Vvedenskaya : Yes, the forces are representing the stresses before and after the shock. The forces considered by Prof. Beloussov are in the whole crust, here I considered them locally.

Prof. Shneiderov : The hypothesis of the Earth's expansion, proposed by myself in 1943, and later by Prof. Egyed (see 27th Session) and others, calls for the tensor which Dr. Vvedenskaya describes in her mechanism of earthquakes. Different diastrophic conditions in different localities of the extended (dilatated) crust may result in a non-uniformity of the direction of the faults, depending on which pair of forces prevail (the pressure of the Earth's expansion from inside, or the dilatation forces in the crust).

122. — *Prof. Byerly* gives his paper : The transformation of elastic strain energy into kinetic wave energy at the source of an earthquake.

The theory by which we connect the motions on our seismograms with the nature of the source postulates a sudden application of some force system at the source. Although some writers, particularly in Japan, feel that such forces can act on a previously unstrained medium, it has been the American view that strain accumulates slowly in the rocks, finally resulting in rupture. The mechanism by which the potential energy of strain is translated into the kinetic energy of wave motion is the problem. The paper discusses various views as to this mechanism.

Dr. Hodgson says that he has tried the last three years to use S waves in focal mechanism studies, but has not succeeded thus far.

123. — *Prof. Knopoff* presents his paper : The statistical accuracy of the fault-plane method.

As a scientific result, the quadrant solutions for the fault-plane method should be assigned statistical accuracies so that an assessment of the significance of the solutions can be made. In particular the accuracy of the solution, expressed as a probable error, will depend upon the number of stations that have observations of first motions in a direction opposite to that determined by considering the majority of stations. Hence, in the solution no data can be omitted because they do not "fit" solution. Stations are assumed to be located exactly ; only the sign of the observed first motions is assumed to have a finite probability of being incorrect. The probability that the sign of the observed first motion is incorrect is taken to be exp-$(S/N)^2$ where S is the amplitude of the motion at the receiver and N is the noise level at the receiver; i. e. we assume that possible inaccuracies in the first motions are due to the presence of noise in a trace — the noise may be microseismic, thermal, or of any other statistical kind. We assume N to be a constant at all stations for lack of better evidence. S is taken to be the theoretical radiation pattern from a displacement dislocation fault. *) The quadrant solution is obtained by maximizing the likelihood of the fit. It is seen that the greatest uncertainty in the solution applies to those stations lying close to the quadrant boundaries ; hence the quadrant solution should not be "forced" to fit these points. The probable error in the solution is obtained by using the computed inaccuracies as weights in a least squares fit where the probability of correctness for a given station is taken to be

$$\mathrm{Log}_e \left[1+\mathrm{erf}\ (S/N)\ \mathrm{sgn}S\mathrm{sgn}R\right]$$

where sgn$R$ is the sign of the reading.

*) L. Knopoff and F. Gilbert : First motions from seismic sources, *Bull. Seism. Soc. Amer.*, Vol. 50, No. 1, 1960, pp. 117-134.

Dr. Scheidegger : Do we have a computer program where one can feed in station data and get out the fault-plane solution ?

Prof. Knopoff : Yes, but only for a small computer. If it is programmed for an IBM 709 machine, it will take about 35 minutes to get the result.

Dr. Hodgson : One must take account of the variation of station accuracy. Galvanometer connections may be reversed (we have found 20 such stations) and many stations, perhaps 20 per cent, consistently produce random observations. We all look forward to the day when quadrant solutions can be made by an electronic computer as part of the epicentral determination. Such a program will have to keep a running score of station accuracy.

Ing. Gershanik : I would like to know if in your calculation you only assign to each observation a weight which is related to the amplitude reported by the station, or if you also take into account that the unknowns of the problem are theoretically connected with the amplitudes, in such a way that these are functions of the azimuths.

Prof. Knopoff : We do not include in the data the station amplitudes. These are subject to wide variations due to variation in magnification, type of rock beneath the station, etc. We use only the theoretical amplitudes for each station ; these are a function of the azimuth.

Father Ingram : 1) Does your method involve the supposition of a trial pair of lines ? — 2) You spoke of four coordinates for the pair of lines, but there is also the orthogonality condition.

Prof. Knopoff : 1) Yes, it simplifies the computation. — 2) We introduce the condition later. You are correct, there are only three variables.

124. — *Father Stauder* presents his paper : S waves and focal mechanisms.

In the usual techniques of fault plane work, observations at the earth's surface are transformed to motion at the surface of a focal sphere. For a great many sources, including a single force and dipoles with and without moment, the motion at the source is coplanar with the direction of the S motion at any given point on the focal sphere. The plane so determined is identical with the plane of polarization of S waves, where by plane of polarization of S is meant the plane containing the ray and the S motion. This plane is determined by the angle $\varepsilon = \tan^{-}$ SH/SV.

Two methods for relating the plane of polarization of S to the mechanism at the focus are proposed. In the first, the trace of the plane of polarization on the focal sphere is projected onto a plane tangent to the sphere at the bottom by means of a central projection. For sources of the type mentioned above, the projections of the planes of polarization determined at many points form a family of straight lines which converge to the projection of the pile motion. For a double dipole with moment source the pattern is more complicated. In the second method the poles of the planes of polarization are plotted on a Wulff net. Since each of the planes of polarization contains the motion at the source, the poles of these planes determine a plane perpendicular to the motion.

The methods are applied to seven earthquakes for which fault plane solutions from P waves were previously determined. In all cases the S wave data agree with the P wave solution. Further, the data conform to the pattern expected for a single dipole with moment source and select one of the P nodal planes as the fault plane. Peculiarities in the scatter in the graphical presentation of the data are discussed.

For three other earthquakes, all in the aftershock sequence of the Kamchatka earthquake of November 4, 1952, the same methods of S wave analysis require a single force mechanism. This result was unexpected. If verified in further instances, it introduces a new element into source determination discussions.

In addition to the publication from the Dominion Observatory, Ottawa, see also the following publications by Father Stauder on the same subject : *Earthquake Notes,* Vol. 29, No. 3, 1958, pp. 17-23 and pp. 24-30 (both with P. Byerly); *Geofisica pura e appl.*, Vol. 44, No. 3, 1959, pp. 135-143 ; *Bull. Seism. Soc. Amer.*, Vol. 50, No. 2, 1960, pp. 293-322 ; Vol. 50, No. 3, 1960, pp. 333-346 and pp. 347-388; Vol. 50, No. 4, 1960, pp. 581-597 ; Vol. 51, No. 2, 1961, pp. 277-292 (the last with W. M. Adams).

Dr. Båth refers to the possible influence of rotation of the plane of polarization of the S waves, as they pass discontinuity surfaces or are reflected against them or as they pass through continuously varying media. A theoretical investigation of this problem will be published by M. Båth in the *Geophysical Journal*, Vol. 4, 1961 ("Special Harold Jeffreys Volume").

Prof. Knopoff : We have calculated the motion to be expected at distance resulting from a point source placed in a continuously inhomogeneous elastic medium. In this theoretical calculation, we have found that SV motions always remain perpendicular to the ray and in an SV polarization. The same holds for SH. We have not calculated the results to be expected for a mixture of SV and SH.

125. — *Dr. Honda* gives his paper : Generation of the seismic waves.

En faisant les hypothèses suivantes :

a) les tremblements de terre se produisent par le dégagement des tensions déviatrices ;

b) l'effet du dégagement est représenté par des forces impulsives radiale et transversale s'exerçant sur la surface d'une cavité sphérique établie autour de la source du tremblement de terre — on fait un calcul théorique concernant les mouvements des ondes P et S, à une grande distance de la source, dans le cas où l'allure du premier mouvement des ondes est du type à quadrants. Le résultat théorique ainsi obtenu est comparé à celui obtenu à partir des enregistrements pour quelques tremblements de terre profonds qui ont eu lieu au Japon.

126. — *Dr. Aki* presents his paper : The use of long-period surface waves for the study of earthquake mechanism.

Rayleigh and Love waves are used for the study of the earthquake mechanism by the method of phase equalization.

A comparative study of Love waves from California shocks with those from Nevada shocks strongly supports the hypothesis of a pair of couples for the earthquake source rather than a single couple.

Source motions of California shocks are derived from Rayleigh waves recorded at stations in the east by the equalization of phase delay due to propagation and recording. It was found that the sense of the source motion thus derived is in agreement with the fault plane solution obtained from the P-wave data.

Source motions of 53 circum-Pacific shocks are derived from Pasadena records of mantle Rayleigh waves. The shape of the source motion is interpreted, under reasonable assumptions, in terms of the direction of the force at the source. The direction of the force shows a systematical distribution which favors the hypothesis that righthand strike slips prevail throughout the circum-Pacific earthquake belt.

This paper consists of the following four papers by K. Aki :

1) The use of Love waves for the study of earthquake mechanism, *Journal of Geophysical Research,* Vol. 65, No. 1, 1960, pp. 323-331.

2) Study of earthquake mechanism by a method of phase equalization applied to Rayleigh and Love waves, *Journal of Geophysical Research,* Vol. 65, No.2, 1960, pp. 729-740.

3) Interpretation of source functions of circum-Pacific earthquakes obtained from long-period Rayleigh waves, *Journal of Geophysical Research,* Vol. 65, No. 8, 1960, pp. 2405-2417.

4) Further study of the mechanism of circum-Pacific earthquakes from Rayleigh waves, *Journal of Geophysical Research,* Vol. 65, No. 12, 1960, pp. 4165-4172.

Dr. Ritsema : Are the solutions presented in agreement with results from P waves ?

Dr. Aki : The earthquakes studied occurred in 1958-1959, and P-wave solutions are not yet available.

127. — *Mr. Brune* presents the paper by *J. Brune, J. Nafe,* and *J. Oliver :* Phase analysis of surface waves to determine initial phases at the origin.

The network of long-period seismographs operated during the IGY made it possible to study the radiation pattern of Rayleigh waves from the S. E. Alaska earthquake of July 10, 1958. A simple method for determining initial phases of surface waves, developed recently at Lamont Geological Observatory was used to determine the azimuthal pattern of initial phases. When this pattern is compared with observed fault motion and the fault plane solution from body waves, it appears that the surface wave pattern for this earthquake bears a simple relation to the fault motion and can be understood in terms of the elastic rebound theory of faulting. The azimuthal pattern of amplitudes was also determined. The use of surface waves for determination of fault motion should prove to be especially valuable in the case of small earthquakes, for the radiation pattern may be found using only stations near the epicenter. The method may be combined with the fault plane solution of body waves to give a more powerful method for the study of faulting mechanism.

The paper will be submitted for publication in *Bull. Seism. Soc. Amer.*

128. — *Dr. Sponheuer* reads the paper by *N. Öcal :* Die Bestimmung des Mechanismus mit der Methode von Byerly-Hodgson bei einigen Erdbeben in Nord- und West-Anatolien.

Avec la collaboration du Dr. John H. Hodgson, en employant la méthode de Byerly-Hodgson, on a déterminé le mécanisme au foyer des trois séismes forts de l'Anatolie qui ont eu lieu en 1957.

Pour les séismes de Fethiye I (24 avril 1957) on a calculé : plan de la faille — vertical ; mouvement — vertical ; "Direction of strike" N29°E, et on a trouvé : le secteur SE a glissé vers le bas, le secteur NW a glissé vers le haut.

Pour les séismes Fethiye II (25 avril 1957) et Abant (26 mai 1957), on a obtenu le "Strike Component" plus grand que le "Dip Component", et le caractère de la faille : "Strike Slip".

The paper will appear in the *Publications from the Seismological Institute of the Technical University, Istanbul.*

129.— Dr. Gaisky reads the paper by *T. I. Kukhtikova :* Dislocations in foci of the Tadjik depression.

1. Dislocations in foci of the Tadjik depression have been defined according to the observed data of the net of seismological stations equipped with seismographs of the "VETIK" type with the magnifications about 16.000—25.000. The high accuracy of the definition of foci coordinates (2-5 km) and encirclement of the foci by the stations being satisfactory enough allowed to consider the problem of confrontation of the dislocations in foci with the faults mapped by the geological methods.

2. The faults in the foci and direction of motions along them have been determined by V. I. Keilis-Borok method; the interpretation has been made according to the first motions of P and S waves (component SH); the direct waves and those refracted at the boundary between the friable sediments and crystalline rock and also at the base of the Earth's crust have been used for the interpretation.

3. The range of the earthquake intensities with which the investigations were made is within the limits of lg E_j = 9-13. The strongest earthquake of the region, occurring on 22/9 1956, had $M = 5.8$ (Uppsala).

4. The findings of motion mechanism of the two strongest earthquakes of the region and their main aftershocks (August 21, 1955, lg $E_j = 13$; 10 aftershocks ; September 22, 1956, lg $E_j = 13$; 30 aftershocks) showed that the mechanism of the motions at the aftershocks repeats that of the initial earthquake in the sense that the general orientation of the fault planes and the direction of block displacements remain unchanged. The nature of motions along the faults is less stable (all possible variants from mere displacement to the steep dipping fault are observed).

5. The confrontation of the foci dynamic characteristics with the geologic ruptures observed in the epicentral zones shows that the majority of ruptures in the foci of Tadjik depression has their orientation and morphology similar to the surface ruptures. The ruptures orientated crosswise to the stretch of the geologic structures are quantitatively of subordinate importance.

6. In the processing, some interesting methodical questions have been considered about the establishment of the source type equivalent to a focus by observations of the initial motions of longitudinal waves and also concerning the estimation of stability of the focus mechanism according to the data of one seismological station.

In addition to its appearance in English in the Publications of the Dominion Observatory, Ottawa, this paper has appeared in Russian in *Trudy instituta seismostoikogo stroitel'stva i seismologii Akademii Nauk Tadjikskoi SSR,* Vol. 6, 1960, pp. 141-150 ; Vol. 7, 1960, pp. 97-102 ; and Vol. 10, 1961 (in press).

Dr. Soloviev : What is the main conclusion from the work ? Is it true, that the Mesozoic structures of the Peter I Mountains move towards north-west and upwards relative to the structures of the Tadjik depression ?

Dr. Gaisky : Yes.

130. — *Dr. Scheidegger* presents his paper : The tectonics of Asia in the light of earthquake fault-plane solutions.

On pourrait raisonner que l'on devrait avoir une corrélation entre la tectonique d'une région et les plans de faille des séismes de cette région. Cette corrélation existe, mais il n'est pas possible de la déterminer facilement. On trouve qu'il faut considérer les directions nodales dans les séismes et on observe que ces directions nodales, en général, sont normales à la direction du déplacement tectonique. En conséquence, il est possible de déterminer la direction du déplacement tectonique par une méthode aux moindres carrés. Cette méthode a été appliquée à des séismes asiatiques pour lesquels des observations nombreuses ont été publiées dans la littérature russe de géophysique. On trouve une uniformité remarquable du déplacement tectonique dans l'Asie continentale qui s'étend de l'île de Sakhaline jusqu'aux Pamirs et aux montagnes du Kopet Dagh. Ce résultat indique une uniformité des forces tectoniques de la croûte terrestre à grande échelle.

In addition to the Publication of the Dominion Observatory, Ottawa, see also *Bull. Seism. Soc. Amer.,* Vol. 49, No. 4, 1959, pp. 369-378.

Prof. Vening Meinesz confirms Scheidegger's findings concerning the movement of the Asiatic continent.

Prof. Knopoff expresses his doubts on the reliability of such far-reaching conclusions, considering the nature of the basic data.

131. — *Mr. Eiby* reads the paper by *G. J. Lensen :* Principal horizontal stress directions as an aid in the study of crustal deformation.

Stress in the earth's crust can be resolved in three components mutually perpendicular in such a way that one of these (the Principal Horizontal Stress) occurs in the horizontal plane, one in the vertical plane and the last one coincides with the intersection of both planes. The PHS direction is taken parallel to the strike of purely normal faults at the surface.

The author (1958 a, b, c ; 1959) has shown that :

(a) The relationship between the strike of major fault and the PHS can be expressed as $H/V = \tan 2\alpha$, where H and V are the horizontal (measured along the strike) and vertical components of displacement, and α or its complement is the angle between the strike of the fault and the PHS direction.

(b) The compressional angle between dextral and sinistral faults is obtuse in compressional and acute in tensional regions.

(c) The PHS direction bisects the compressional angle.

(d) The PHS directions over a large area (e.g. New Zealand) show a consistent pattern.

In the present paper PHS directions, based both on fault data and fault plane solutions, are given for the Circum-Pacific (fig. 4). The provisional stress pattern shows that in the Eastern Pacific the PHS directions are approximately N-S and swing to an E-W direction near the equator, while the PHS directions in the Western Pacific are reversed, being approximately E-W in temperate regions and swinging to a N-S orientation near the equator, thus showing an additional difference between both sides of the Pacific.

References to papers by G. J. Lensen (in addition to the Publications of the Dominion Observatory, Ottawa):

1) Rationalized fault interpretation, *New Zealand Journ. Geol. Geophys.*, Vol. 1, 1958a.

2) Note on the compressional angle between intersecting transcurrent clockwise and anticlockwise faults, *New Zealand Journ. Geol. Geophys.*, Vol. 1, 1958b.

3) Measurement of compression and tension : some applications, *New Zealand Journ. Geol. Geophys.*, Vol. 1, 1958c.

4) Secondary faulting and transcurrent splay-faulting at transcurrent fault intersections, *New Zealand Journ. Geol. Geophys.*, Vol. 2, 1959.

Prof. Vening Meinesz : Stresses found in Indonesia do agree well with Lensen's picture, though the stress direction is SSE instead of SSW.

132. — *Dr. Ritsema* gives his paper : Further focal mechanism studies at De Bilt.

A table is presented with 79 new earthquake fault plane solutions determined at De Bilt since 1957. S wave data of South-East Asian and West Pacific shocks show that the majority of the investigated earthquakes can be considered as being caused by a single force couple in the focus. Some system can be found in the directions of the A-, B- and C-axes of the solutions of the various seismic zones.

Solutions, based on longitudinal wave data only, are not selective with respect to a single or a double force couple acting in the focus. If the earthquakes of the Circum-Pacific seismic zones are considered to be caused by a double force couple in the focus, or by an equivalent system of maximal and minimal pressures, there is some evidence that the directions of maximal pressure are non-random.

It is understood that many more detailed studies are needed.

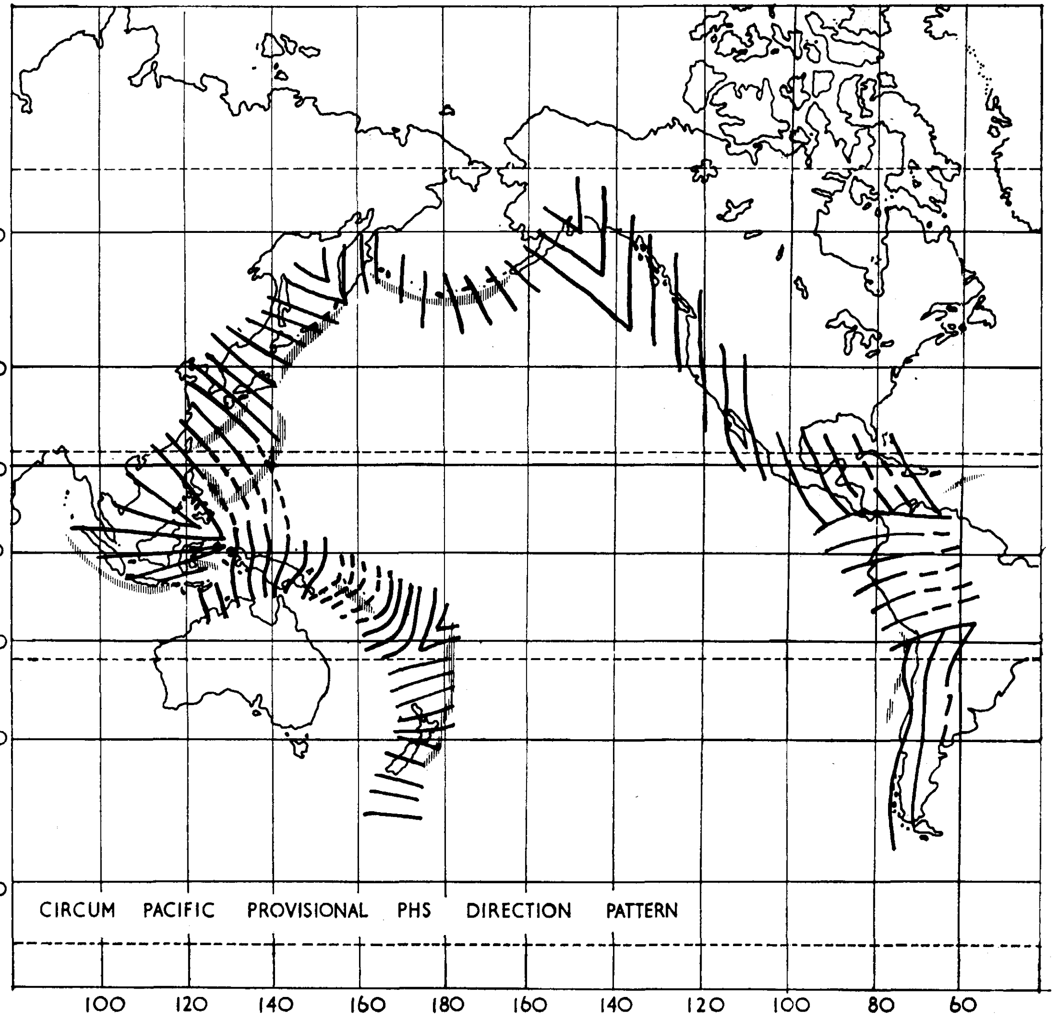


Fig. 4. — Circum-Pacific provisional PHS direction pattern, according to G. J. Lensen (paper 131).

Prof. Vening Meinesz : The results found by Ritsema from the seismological data in Indonesia fit very well with the direction of horizontal crustal compression derived from the gravity results in this archipelago.

133. — *Father Ingram* gives his paper : Generalized focal mechanism.

The mechanism considered is that of three couples without moment, or double forces. This is a generalization of the system of Honda and is intended as a suggested mechanism for the cases when the usual investigation by fault-planes fails. Expressions are given for the amplitudes of P, SH and SV recorded in the usual way at extended distances. It is found that a cone of the second degree separates the compressions and dilatations, instead of the pair of orthogonal planes. The corresponding surfaces for zero SH and for zero SV are also given and can be used when the signs of the corresponding movements can be identified. The projection of these surfaces on the central diametral plane is examined and some of the geometrical properties noted. In particular, it is found that the projection of the S-wave passes through a fixed point if two of the couples are equal. The zero locus of P in this plane is a conic, that is the curve separating the compressions and dilatations. Where two lines can be drawn to separate the compressions and dilatations, it is evident that a hyperbola will also suit and may give in some cases a better result. This would be evidence of the existence of the third couple, which might be small.

The session is closed at 12.30.

22nd SESSION

WEDNESDAY, AUGUST 3 (afternoon)

Program

1. — Scientific communications : Ultra-Long-Period Motions in the Earth and Recent Movements of the Earth's Crust.

   134. — *M. V. Gzovskii :* Tectonophysics and earthquake forecasting.

   135. — *C. Lomnitz :* Deux notes sur la théorie des tremblements de terre.

   136. — *N. Hast :* Rock pressure measurements. Horizontal stresses in the Earth's crust.

   137. — *B. A. Petrushevsky* and *I. A. Rezanov :* On some pecularities of the latest tectonic motions of the Verkhoyansk-Kolyma folded region.

138. — *W. B. Myers :* Crustal deformation accompanying the earthquake of August 18, 1959, in southwest Montana.

139. — *C. Lomnitz :* Tensions et déformations à l'intérieur d'une planète froide.

140. — *F. A. Vening Meinesz :* Crustal movement in the Netherlands.

This symposium is held together with IAG. It is opened at 15.00 under the chairmanship of *Prof. Tsuboi.*

1. — Scientific communications : Ultra-Long-Period Motions in The Earth and Recent Movements of the Earth's Crust.

134. — *Dr. Gzovskii* gives his paper : Tectonophysics and earthquake forecasting.

Some investigators of Middle Asia have developed a new method of earthquake forecasting — the precise seismic regioning in scale 10^{-5} indicating the earthquake intensity and frequency. For each elementary area (from 100 to 1,000 km^2) it is required to determine the linear relationship between the logarithm of mean frequency (ln N) and the logarithm of energy (ln U). Each plot has an upper limit of earthquake energy (U_{ma}). Tectonophysics gives a possibility of quantitative interpretation of the geological data and instrumental seismostatistics.

Hypothesis I. The upper limit of energy U_{max} depends chiefly on the maximum value of velocity gradient of tectonic movements (grad $V)_{max}$ and of maximum strike-extent of individual tectonic fault l_{max}:

$$U_{max} \approx 2\, n\, \omega \lambda\, \Phi^2 \frac{\eta^2}{G_1} l^3_{max} (\text{grad } V)^2_{max} \qquad (1)$$

where η = viscosity coefficient ; G_1 = shear modulus of quasi-instantaneous elasticity; Φ = proportionality coefficient between the rate of deformation of matter at depth and the velocity gradient of the Earth's surface tectonic movement ; λ = the ratio between the volume of earthquake focus and l^3 ; ω = the coefficient indicating what part of potential energy of quasi-instantaneous elastic deformation is released at the appearance or renewal of the fracture ; n = coefficient indicating what part of the released energy is transformed into seismic wave energy. Calculations according to (1) and seismological and tectonic data given by field investigations and model testing show a satisfactory agreement. For example for Middle Asia (B = intensity) :

Measured in the field:	Studied by model testing:	Calculated by (1):
(grad $V)_{max}$ = 5 . 10^{-7} year^{-1}	$\Phi = 3$	$U_{max} = 10^{23}$ erg
l_{max} = 30 km	$\lambda = 1$	if focal depth =
$G_1 = 3 . 10^{11}$ dyn/cm^2	$\omega = 0.1$	10-20 km
$\eta = 0.01$	$\omega \lambda \Phi^2 = 0.9$	
B_{max} = 9 degrees		B_{max} = 9 degrees

Hypothesis II. In the zones with homogeneous structure and permanent deformation regime, the differences in earthquake energy are a function only of the dimension (length of strike) l of tectonic faults. If the ratio between the decrease of logarithm of fault number $-\Delta \ln N$ and the increase of logarithm of strike length $= +\Delta \ln l$ is indicated as

$$\frac{-\Delta \ln N}{\Delta \ln l} = 3\nu \tag{2}$$

then ν is the angle-coefficient in a linear frequency-energy diagram :

$$\Delta \ln N = -\nu \Delta \ln U$$

Hypothesis III. The increase of velocity gradient $(\text{grad } V)_m$ compared to its standard value $(\text{grad } V)_0$ indicates the increase in frequency of earthquakes $N_m(u)$ with a definite energy U :

$$\ln N_m(u) \approx \ln N_0(u) + \frac{2\eta\Phi}{\xi}[(\text{grad } V)_m - (\text{grad } V)_0] + 2\nu \ln \frac{(\text{grad } V)_m}{(\text{grad } V)_0} + \nu \ln L \tag{3}$$

The frequency $N_0(u)$ corresponds to the standard $(\text{grad } V)_0$. One must take account also of the following factors : the type of tectonic deformation Φ; the viscosity of the Earth's crust (η); the ratio (ξ) showing the dependence of strength on the logarithm of the stress duration ; the general extent L of zone including numerous faults.

Hypothesis IV. The above-mentioned factors may be related to the energy of earthquakes $U_m(N)$ corresponding to a standard frequency N

$$\ln U_m(N) \approx \ln U_0(N) + \frac{2\eta\Phi}{\nu\xi}[(\text{grad } V)_m - (\text{grad } V)_0] + 2 \ln \frac{(\text{grad } V)_m}{(\text{grad } V)_0} + \ln L \tag{4}$$

Here $U_0(N)$ is the energy corresponding to $(\text{grad } V)_0$. The $U_m(N)$ must not be greater than U_{max} from (1). The intensity of earthquakes $B_m(N)$, expressed in degrees, may be determined by using $\ln U_m(N)$. These earthquakes have the standard frequency N. It is the best way to characterize the seismic danger for buildings.

Hypothesis V. The anisotropy of the crustal mechanical properties arises as a result of the long-term tectonic deformations. When the deformation in a new direction begins, the values of the mechanical properties change (the viscosity increases). Therefore, in this case according to (3) and (4) the frequency and the energy of earthquakes may be considerable in spite of the low value of the velocity gradient.

See also *Bull. Sov. Seism., Akad. Nauk SSSR*, No. 8, 1960, pp. 67-72.

135. — *Prof. Lomnitz* gives his paper : Deux notes sur la théorie des tremblements de terre.

I.

Une discussion quantitative de la théorie de l'accumulation des déformations comme cause des séismes mène aux conclusions suivantes :

1. La relation magnitude-fréquence apparaît comme un invariant fondamental du mécanisme séismique ;

2. L'hypothèse de l'accumulation des déformations n'explique pas l'existence des grands séismes ;

3. La forme logarithmique de la courbe des répliques ne reflète pas nécessairement la variation des déformations dans l'écorce.

II.

On envisage une planète comme un système thermodynamique ouvert et continu ayant un nombre indéfini de variables d'état. Une des variables, par exemple la température, se maintient constante pour considérer une séquence séismique. Il s'ensuit un régime permanent de premier ordre, qu'on analyse avec les résultats suivants :

1. La production d'entropie augmente dès qu'on introduit une perturbation de pression correspondante à un séisme ;

2. Ce processus s'accompagne de transport de matière vers la région perturbée ;

3. L'énergie dépensée pour réduire la perturbation est proportionnelle au logarithme du temps écoulé depuis l'instant du séisme ;

4. Toute accumulation de déformation serait subordonnée à la distribution mondiale d'énergie ;

5. Les répliques devraient suivre la courbe d'influx d'énergie dans la région perturbée, ainsi que se propager de la faille vers le dehors.

6. On n'éprouve pas de difficulté à expliquer l'existence de grands séismes par cette théorie.

136. — *Prof. Hast* presents his paper : Rock pressure measurements. Horizontal stresses in the Earth's crust.

A method is described according to which the absolute value of stresses in rock can be measured in bore holes at places and depths in the solid Earth's crust which can be reached in mines. The stress ellipsoid in the rock can be determined and we then know the three principal stresses and their directions, the three principal shearing stresses and the directions of the six planes along which they act. In this way it is possible to get a complete description of the stress conditions in the undisturbed rock at every point measured in the solid Earth's crust. By measurements made in different areas of the earth it will be possible to find out general facts about the forces which act in the upper part of the crust.

Since 1953 I have used my method of absolute stress measurement in rocks in the determination of the stress conditions in 10 mines in Sweden and Norway. Between 6000 and 7000 separate stress readings were made in this research work. The remarkable fact was found that there exists — almost over all Scandinavia — *a horizontal pressure in the Earth's crust which is about 4 times as high as the own weight* of the rock above the point of measurement ; locally much higher values are found. The measurements were made down to a depth of 1000 metres.

The results show that the horizontal stresses in the Scandinavian area increase with depth — in any case down to 1000 metres — according to a simple mathematical relation. This relation shows how the uppermost part of the crust is functioning from a stress point of view. However, along the Norwegian coast to the Atlantic Ocean there is probably a crust zone where the stresses are small or zero.

Another exception is a Swedish mine located near an area where the secular uplift of the crust in Scandinavia is at its maximum. In this mine the crust is overstressed in a horizontal direction. A small earthquake may be the effect in such overstressed areas when a sudden burst appear in the stressed rock material. The rock will be split up by fissures, as a rule horizontal ones. This rock-burst situation can appear in the rock in a small or large scale.

It seems probable that such high horizontal stresses as those measured in Scandinavia are present in the Earth's crust, almost over the whole Earth. As nowadays it is practicable to measure rock pressures very accurately, it should be of great value to start a mapping of the horizontal stresses acting in the Earth's crust in different continents.

In such areas where the crust is highly overstressed horizontally the risk of earthquakes can be higher than in areas where the horizontal stresses are of normal magnitude. Moreover, such measurements might give some new aspects on the earthquake problem in general and on the application of mathematical calculations on it.

The complete paper is being prepared for publication and will probably be submitted to *Geofisica pura e applicata.* Earlier related publications by Prof. Hast have appeared as follows :

1) Bergtrycksmätningar i gruvor, *Jernkontorets Annaler,* Stockholm, Vol. 141, 1957, pp. 633-745.
2) The measurement of rock pressure in mines, *Sveriges Geologiska Undersökning, Årsbok 52,* 1958, No. 3, 183 pp.

Dr. Båth : The method of Prof. Hast, originally developed to determine the stability of mines, has given results of great geophysical significance — especially the finding of large horizontal stresses in Scandinavia. Considering this result and the fact that stress measurements are missing from most parts of the world, I suggest extending these measurements over the globe.

Prof. Goguel refers to the glaciation of Scandinavia as a possible reason for the stresses found.

Prof. Hast : The uplift of the North that is taking place at present has been said to be a reaction to depression during the ice age. However, according to the most recent findings of scientists in this field, practically nowhere in the world does the level of crust remain unchanged over a considerable period, irrespective of whether or not there has been a recession of ice. The horizontal pressures

I have found in Scandinavia are probably present in the crust around the whole Earth. However, in some areas I think they are locally influenced by bending of the crust caused by secular movements.

Dr. Blanchard : Does the vertical component of stress measured always agree with the hydrostatic pressure at the various depths of measurements ?

Prof. Hast : If the stress is absolutely horizontal the cells measure the vertical load of the overburden. In fact, the accuracy of the result is shown to be so good that it is possible to determine the weight per unit volume of the strata above the point of measurement.

Dr. Bott : Away from local disturbances, is there any indication of a consistent pattern in the directions of the principal pressures ?

Prof. Hast : Yes, there is. The directions of the principal stresses are about east-west and north-south. In normally stressed areas, east-west is the direction of the major principal stress. In the under-stressed area, near to the Atlantic Ocean, east-west is the direction of the minor principal stress (at Malm it is = O). The same is valid in the overstressed area of Vingesbacke.

Prof. Vening Meinesz : I am not surprised about the presence of much stronger horizontal stresses in the crust in Scandinavia than the hydrostatic pressure. There are a great number of indications that we live in an orogenic period, which must be characterized by such strong horizontal stresses in the crust. I think these horizontal crustal stresses are caused by the drag exerted on the crust by convection currents in the mantle (see further the 27th Session).

137. — *Prof. Petrushevsky* presents the paper by *B. A. Petrushevsky* and *I.A. Rezanov :* On some peculiarities of the latest tectonic motions of the Verkhoyansk-Kolyma folded region.

1. According to some investigators the Verkhoyansk-Kolyma folded region should be ranked among such structures as the Altai, Sayany, etc. by the nature of their latest tectonic motions. The authors think this conception incorrect.

2. Considering peculiarities of the development of this territory at a time preceding the Neogene-Quaternary epoch, it should be underlined that the termination of the geosyncline regime (Upper Jurassic-Lower Cretaceous) was not accompanied by orogeny. The tectonic motions of the Upper Cretaceous-Paleogene epoch in the Verkhoyansk-Kolyma region were not at all differentiated and bore the character of typical platform motions.

3. Judging from a very slow development and small thickness of the Neogene-Quaternary sediments, the nature of these motions at the time much resemble motions peculiar for the region in the Upper Cretaceous-Paleogene epoch (the Okhotsk Sea coast excluded).

4. The study of the relics of the ancient surface levelling, widely developed in the Verkhoyansk-Kolyma region also proves that no differentiated motions occurred at the Neogene-Quaternary epoch ;

on a vast space the relics are observed at one and the same altitude (1,200-1,400 m), being lofty (up to 2,000 m) only in some places (Suntar-Khayata).

5. In their differentiation, the motions of the Neogene-Quaternary epoch are very similar to those on the platforms, but the total, more or less regular, elevation of the country for this period is rather significantly different from what is usually observed on the platforms. It was the subsequent erosion dismemberment that created an impression of high contrast late motions.

6. Thus, if during the Upper Cretaceous-Paleogene epoch the Verkhoyansk-Kolyma region was characterized by a platform regime, the Neogene-Quaternary epoch was marked by two specific peculiarities : it differed from the platforms by the value of total elevation but is extremely similar to them by a small differentiation of motions.

The paper has been published in *Doklady Akad. Nauk SSSR,* Bd 133, No. 5, 1960, pp. 1173-1175.

138. — *Mr. Myers* gives his paper : Crustal deformation accompanying the earthquake of August 18, 1959, in southwest Montana.

During this major earthquake ($M = 7.1$) an area 27 miles long and 14 miles wide subsided detectably. Maximum instrumentally determined subsidence was 19 feet ; a tract of at least 50 square miles dropped more than 10 feet. There was almost no elevation above previous levels, and it is thought that there was little or no horizontal displacement. The contours of subsidence (determined by relevelling of benchmarks by the U.S. Coast and Geodetic Survey, tilting of lakeshores, and heights of new fault scarps) define a broad basin that plunges gently eastward, directly across the structural elements of the Madison Valley and the Madison Range to Hebgen Lake. The basin of new subsidence is terminated obliquely and abruptly, northeast of Hebgen Lake, against high (5-20 feet) reactivated fault scarps. The south flank of the structure of subsidence is a gently sloping platform, broken by small (0-2 feet) reactivated fault scarps, most of which face the subsidence basin.

Both large and small fault scarps mostly follow faults upon which there had been previous Quaternary displacement. Of the three high scarps, two are in areas of Paleozoic sedimentary rocks, the third cuts thick Pleistocene deposits which mask the pre-Tertiary structures. The two major scarps in consolidated rocks are on faults more or less rigorously controlled by the attitude of bedding. These scarps are limited in extent to areas where the bedding attitudes dip steeply towards the subsidence basin. Where the bedding attitudes deviate from orientations suitable for gliding planes to accommodate the subsiding volume of surface rocks, the scarps dwindle, to discontinuous scarplets or completely die out. At one locality where a major arcuate scarp forms the limit of the subsidence area, the change of bedding attitude and concommital dwindling of the scarp is matched by a relatively narrow belt of warping without observed ground breakage, that proxies for the fault displacement and forms the margin of the subsided area.

The control of these scarps by favorably oriented bedding in the sedimentary blanket shows that the fault pattern at the surface cannot directly indicate the pattern of deep basement deformation.

Though an attempt has been made to gather evidence of previous slow level changes in the Hebgen Lake area no reliable data have yet been found.

The paper will be published as a *U.S. Geol. Survey, Professional Paper.*

Prof. Lomnitz asks for the relation between intensity and ground movement.

Mr. Myers : In a general way the observable structural damage to buildings etc. correlates well with ground movement. The total amount and degree of structural damage was surprisingly low.

Prof. Rothé questions the location of the epicenter.

Mr. Myers : It seems probable that the plotted epicenter is somewhat in error and in reality the focus lies beneath the subsided basin rather than outside it. The U.S. Geological Survey recorded aftershocks over a period of several days with portable equipment. Most of the epicentral locations are within the basin of subsidence.

139.— Prof. Lomnitz presents his paper : Tensions et déformations à l'intérieur d'une planète froide.

Si l'on admet que la Terre était à l'origine un corps froid, la distribution des tensions à l'intérieur n'est pas nécessairement hydrostatique et la solution de Love pour la sphère élastique homogène redevient d'un certain intérêt.

On donne des solutions pour une planète froide ayant les dimensions de la Terre et la distribution des densités et des vitesses des ondes P et S qu'on y suppose. La surface de déformation radiale nulle se trouve alors à 700 km de profondeur. Cependant cette surface n'est pas une discontinuité quant aux tensions. Les valeurs différentielles seraient de $0{,}9 \times 10^5$ bars à la surface et de 6×10^5 bars au bord du noyau. La pression au centre de la planète, en supposant une distribution hydrostatique à l'intérieur du noyau, serait de l'ordre de 14×10^5 bars.

Dr. G. Jobert : Le calcul présenté est celui de la déformation produite dans une Terre élastique initialement nongravitante par l'introduction brusque de la gravitation. Si la Terre s'est effectivement produite par accrétion de particules, la gravité devait être constamment présente; la répartition réelle des tensions internes peut être en conséquence fort différente de celle du modèle étudié.

Prof. Lomnitz : Comme je l'ai remarqué, ce modèle constitue à mon avis un cas limite extrême. La répartition réelle des tensions se trouverait entre cette solution et la solution hydrostatique. La déformation subie par une planète dans la période d'accrétion graduelle est évidemment très difficile à calculer.

140. — *Prof. Vening Meinesz* gives his paper : Crustal movement in the Netherlands.

No summary or reference is available.

The session is closed at 17.30.

23rd SESSION

THURSDAY, AUGUST 4 (morning)

Program

1. — Scientific communications : Instruments.

141. — *J. Hamilton :* Trends in seismological instrumentation.

142. — *G. Sutton* and *J. Oliver :* Long-period seismographs.

143. — *P. Pomeroy* and *G. Sutton :* The use of galvanometers as band-rejection filters in electromagnetic seismographs.

144. — *P. L. Willmore :* A wide-band seismograph system for analogue recording.

145. — *S. Gershanik :* Effect of inductive coupling between seismograph and galvanometer.

146. — *A. G. Moskvina* and *N. V. Shebalin :* Calcul des caractéristiques optima du séismographe électromagnétique pour les stations aux parasites certains.

147. — *B. Luskin* and *J. Ewing :* Ocean-bottom seismographs.

The session is opened at 9.05 under the chairmanship of *Dr. Oliver.*

1. — Scientific communications : Instruments.

141. — *Mr. Hamilton* gives his paper : Trends in seismological instrumentation.

New developments in seismological instrumentation are presented and discussed. Specific items covered are : Seismometers, galvanometers, amplifiers, recorders and timing systems. Background information, construction details and performance characteristics are given for each instrument. Sample seismograms obtained with various combinations of instruments are shown.

The paper as presented will not be published, but papers on several instruments discussed in the paper will probably be submitted for publication in *Bull. Seism. Soc. Amer.*

Prof. Hales : What are terminal voltages of seismometers described ?

Mr. Hamilton : I. Benioff seismometer (100 kg mass), $T_O = 1.0$ sec, 8 coils with internal resistance of 125 ohm each : terminal voltage across damping resistance = 1.0 millivolt/coil/micron of earth motion at 1 cps.

II. Benioff small seismometer (15 kg mass), $T_O = 1.0$ sec, 8 coils with internal resistance of 125 ohm each : terminal voltage across damping resistance = 0.2 millivolt/coil/micron of earth motion at 1 cps.

III. Johnson-Matheson seismometers (20 kg mass), $T_O = 1.25$ sec, one coil with internal resistance of 100 ohm and external critical damping resistance of 100 ohm : terminal voltage across damping resistor approximately = 0.2 millivolt/micron of earth motion at 1 cps.

IV. Melton seismometer (approx. 10 kg mass), T_O adjustable 2-4 sec, one coil with internal resistance of 500 ohm and external critical damping resistance about 1000 ohm : terminal voltage across damping resistor approximately = 0.75 millivolt/micron of earth motion at 1 cps.

Dr. Willmore : I should like to point out three differences between the auxiliary coil calibration unit and the Maxwell bridge method, which uses the transducer coil itself as the driver. The Maxwell bridge eliminates the need for a separate calibration of the force constant of the auxiliary coil, it eliminates the need for a separate pair of wires leading to the seismometer, and it enables one to determine not only the overall response of the system, but also to determine the resonance curve of the seismometer as it would be if the galvanometer were disconnected. This last facility gives a very sensitive check on the seismometer performance, for many seismometers have an extremely sharp resonance when the damping effect of the galvanometer is removed. For fixed-station operation by semi-skilled personnel, a pre-balanced Maxwell bridge can be left permanently in circuit, so that the circuit does not have to be disturbed for the purpose of the calibration. See further *Bull. Seism. Soc. Amer.*, Vol. 49, No. 1, 1959, pp. 99-114.

142. — *Dr. Sutton* presents the paper by *G. Sutton* and *J. Oliver :* Long-period seismographs.

Several types of long-period seismographs are operated at the Palisades station of the Lamont Geological Observatory and at other stations throughout the world in continuation of a cooperative program set up during the IGY. Comparison of the seismograms from these instruments and of their magnification curves illustrates their value in the observation of long-period components of body and surface waves. Using the same basic seismometers, a variety of frequency response characteristics are obtained by varying the period, damping, and coupling of the seismometer and galvanometer. An extra galvanometer is used as a band-rejection filter to effectively remove intermediate-period storm microseisms from high magnification long-period seismograms. A tightly coupled system records microseisms in the 10-30 second period range almost continuously. Electronic amplification and filtering, including twin "T" band-rejection filtering, is used in place of long-period galvanometers in some systems. A 200-foot horizontal component strain meter, 1850 feet below surface in a mine, at Ogdensburg, New Jersey, records long-period earthquake waves and microseisms as well as earth tidal strains.

The paper has been published under the title "Seismographs of high magnification at long periods" in *Annales de Géophysique*, Vol. 15, No. 4, 1959, pp. 423-433.

143. — *Dr. Pomeroy* gives the paper by *P. Pomeroy* and *G. Sutton :* The use of galvanometers as band-rejection filters in electromagnetic seismographs.

The large-amplitude intermediate-period, 4-9 seconds, microseisms are effectively removed from high-magnification long-period seismograms with maximum magnification near 50 seconds period. This has been accomplished by the use of a galvanometer of natural period in the microseism range as a band-rejection filter. Addition of the filter galvanometer greatly increases the usefulness of these instruments for studies of long-period microseisms and for clear detection and resolution of the long-period components of both body and surface waves from small shocks at very great distances. Magnification equations and theoretical magnification curves show that extremely high sensitivities for desired periods and low sensitivities for undesired periods can be obtained by combining one or more filter galvanometers in seismograph systems, varying the damping constants and natural periods of the components, and varying the coupling between the components. Also, by proper choice of instrument parameters, undesired periods can be rejected without appreciable modification of the seismograph magnification for periods outside the rejection band.

The paper has been published in *Bull. Seism. Soc. Amer.*, Vol. 50, No. 1, 1960, pp. 135-151.

Prof. Press : Dr. Pomeroy has pointed out the advantages of high-gain long-period seismographs with efficient microseism rejection filters. Prof. Benioff has recently devised a system to accomplish this, using D. C. amplifiers and band-pass filters. To his surprise the microseisms were so well filtered that a major new source of noise appeared — surface waves from numerous small earthquakes which previously were unrecorded. Have you had a similar experience ?

Dr. Pomeroy : Yes. At present there are approximately five earthquakes per day recorded on the standard instruments at Palisades. However, on certain days, the entire record may be taken up with earthquake surface waves or with 20 second microseismic noise which may be of earthquake origin. It would seem that the best way to separate out overlapping earthquakes such as these would be to make array studies to determine direction of approach.

Dr. Shebalin asks how magnification curves are determined.

Dr. Pomeroy : The curves shown during the paper are theoretically computed. However, the theoretical curves have been compared with experimentally determined curves in order to determine the absolute magnifications.

144. — *Dr. Willmore* presents his paper: A wide-band seismograph system for analogue recording.

Nous décrivons les techniques d'enregistrement des mouvements de la terre couvrant une très grande gamme de fréquence et pour l'enregistrement continuel de trois composantes sur bande magnétique. Ces bandes sont repassées à grande vitesse en tenant compte de la filtration et du mélange des composantes enregistrées en n'importe quelles proportions voulues, permettant ainsi l'isolement de n'importe quel secteur composant désiré dans n'importe quelle gamme de fréquence voulue.

The paper will appear under the title "Some properties of heavily damped electromagnetic seismographs" in the *Geophysical Journal,* Vol. 4, 1961 ("Special Harold Jeffreys Volume").

Mr. J. Hamilton : 1) What was tape speed of magnetic tape recorder ? — 2) What overall dynamic range do you expect ? — 3) How is time determined on magnetic tape record ?

Dr. Willmore : 1) 0.05 inches per second. — 2) 70 db is the target. Our present system, which makes no provision for eliminating wow and flutter, yields a little over 40 db. — 3) The constant-frequency tone which is used for flutter control has its amplitude modulated by a digital clock. This system enables us to identify any minute up to a total of 500 days.

145. — *Ing. Gershanik* gives his paper : Effect of inductive coupling between seismograph and galvanometer.

L'amplification dynamique des sismographes électromagnétiques est, comme on le sait, peu uniforme, même avec $T_s \neq T_g$.On montre que si l'on fait un accouplement inductif entre le galvanomètre et le sismographe, au lieu de la faire resistif comme d'habitude on peut gagner beaucoup en uniformité pour $0 < T \leqq T_0$; $T_g > T_s$.A ce but on doit choisir convenablement les rapports : d'amortissements du sismographe et du galvanomètre, des périodes propres de ces appareils, et des inductances et résistances des circuits. Les rapports suivants sont conseillables : $T_s = \frac{1}{2} T_g$; $h_g = 0{,}2$; $h_s = 0{,}7$; L (Henry) $\approx 10^{-3} R$ (Ohms). La sensibilité de l'ensemble sismographe-galvanomètre est proportionnelle au dernier rapport ; pour ne pas l'affecter on peut préamplifier électroniquement la f. e. m. induite dans la bobine du sismographe, ou aussi augmenter le champ dans lequel celle-ci se déplace.

The paper is expected to appear in *Geofisica pura e applicata.*

146. — *Dr. Shebalin* reads the paper by *A. G. Moskvina* and *N. V. Shebalin :* Calcul des caractéristiques optima du séismographe électromagnétique pour les stations aux parasites certains.

1. Dans la plupart des stations séismiques l'augmentation de l'amplification des séismographes est rendue impossible en raison des parasites très élevés. D'ordinaire les parasites séismiques n'embrassent

pas le diapason tout entier des périodes de travail des séismographes il en résulte qu'il y a un moyen d'augmenter l'amplification dans un certain intervalle des périodes.

2. Le spectre des parasites en diapason des périodes de 0,1 à 5-7 sec. (parasites provoqués par le vent et parasites industriels, microséismes) a été étudié dans plusieurs stations séismiques de l'URSS à l'aide de l'appareillage spécial transportable. Les parasites à longue période (inclinaisons, etc.) n'ont pas été étudiés spécialement.

3. Le niveau des parasites dans les diverses stations est très différent ; pourtant la vue générale de la dépendance des amplitudes des parasites de leur période est la même pour toutes les stations, elle se caractérise 1) par un ou deux maxima à l'intervalle des périodes de 0,1 à 0,6 sec. (les amplitudes maxima aux stations différentes varient de 0,01 à 0,1 μ), 2) par un minimum brusque pour les périodes 0,6—2 sec. (les amplitudes maxima : 0,003 à 0,1 μ) et par un maximum pour les périodes ordinaires des microséismes (3—8 sec. avec des amplitudes de 0,1 à 1 μ et davantage).

4. Ces conditions étant données la courbe de l'augmentation avec maximum pour les périodes à 1 sec. environ est la plus avantageuse pour les séismographes à haute sensibilité. Pourtant pour chaque cas il est désirable qu'on fasse un choix individuel de la courbe d'augmentation afin que l'amplitude des parasites sur le séismogramme ne dépasse pas 0,2—0,3 mm pour les périodes de 1 sec. et 0,5—0,7 mm pour les périodes de 3—5 sec.

5. Pour les séismographes électrodynamiques composés d'un pendule et d'un galvanomètre fonctionnant sans amplificateurs la forme de la courbe de l'augmentation peut être déterminée par les paramètres principaux : par les périodes du pendule et du galvanomètre T_1 et T_2 par leurs amortissements $D_1 = \varepsilon_1 / n_1$, $D_2 = \varepsilon_2 / n_2$ et par le coefficient de la liaison électrodynamique σ^2 et la valeur de l'augmentation normale

$$\overline{V} = \frac{2A}{l} \sqrt{\frac{K_1}{K_2}} \sqrt{\frac{D_1 T_2}{D_2 T_1}} \sigma^2$$

où K_1 et K_2 sont les moments d'inertie du pendule et du galvanomètre.

En raison des propriétés du séismographe électrodynamique ayant des périodes très petites des oscillations du sol l'amplification du séismographe $V = \text{Const.}\ T$, avec de très grandes périodes $V = \text{Const}/T^3$. L'augmentation maximum du séismographe V_{max} ne doit pas dépasser trop l'augmentation normale V car des phénomènes de résonance surgissent dans le système pendule-galvanomètre.

6. Les auteurs ont proposé (et les stations séismiques utilisent) la méthode suivante de calcul des caractéristiques optima des séismographes électrodynamiques selon le niveau des parasites :

a) d'abord on dresse une courbe du spectre des parasites ;

b) ensuite tenant compte des pp. 4 et 5 on choisit la forme de la courbe d'amplification ;

c) et enfin à l'examen de la courbe d'amplification (d'après quelques points caractéristiques) on fait le calcul des paramètres du séismographe.

The paper has appeared in *Izv. Acad. Sci. USSR, Ser. Geofiz.*, No. 11, 1958.

147. — *Prof. Ewing* reads the paper by *B. Luskin* and *J. Ewing*: Ocean-bottom seismographs.

In the first phase of a program to establish a network of ocean-bottom seismograph stations, a telemetering seismograph was installed in 2700 fathoms and recordings made aboard ship of a 50-mile seismic refraction profile. Aside from the structural information obtained, two significant results are reported: (1) The measured seismic background noise level is less than 1 millimicron at 1 cps; (2) The measured velocity of shear waves in the upper mantle is 4.27 km/sec. The low measured seismic background and the successful operation of the instrumentation indicate a promising field of application for the telemetering technique.

In this connection a paper by J. Oliver with the same title should be mentioned. It was published in the *Report of the Panel on Seismic Improvement, The Need for Fundamental Research in Seismology,* 1959, pp. 134-136.

Dr. Båth refers to the symposium on microseisms in the Vatican in Rome in 1951, when it was suggested to use ocean-bottom seismographs in order to study microseisms *(Pont. Acad. Sci., Scripta Varia,* Vol. 12, 1952). It is really nice to see that this program is now being realized.

The session is closed at 11.40.

24th SESSION

THURSDAY, AUGUST 4 (afternoon)

Program

12.— Commission of the IGY (President: Prof. Beloussov; presentation of reports of subcommissions and discussion).

13.— Report of Nomination Committee. Election of Bureau and Executive Committee.

14.— Report of Finance Committee.

15.— Report of Publication Committee.

16.— Report of the Committee for the ISS (Dr. Stoneley).

17.— Report on magnitudes (Prof. Richter).

18. — The "Mohole project" (Dr. Maxwell).

19. — The "upper mantle project" (Prof. Beloussov).

20. — Discussion of resolutions to be presented to the IUGG.

The session is opened at 14.40 under the chairmanship of the President, *Sir Harold Jeffreys.*

12. — Commission of the IGY.

Prof. Beloussov, President of the Commission, gives a report, discussing various problems in the preparation of the volume of seismology of the Annals of the IGY, including the question of the future flow of seismic data to the WDC. The Commission of the IGY gives the following recommendations (see also the 8th Session):

1) The commission decides that the final manuscripts of the different chapters should be finished at the end of 1960.

2) The national reports for the introductory chapter should be sent to the President of the Commission, Prof. Beloussov, as soon as possible and not later than October 1, 1960.

The introductory chapter should also indicate how microseismic data were collected and refer the reader to W.D.Cs.; an appendix should list data available in the W.D.Cs.

3) Individual chapters on microseisms should summarize studies already made and recommend other regional studies.

4) With regard to small shocks in the Arctic and in the Antarctic for which the epicentres cannot be located it is decided to send all data to the WDC : A, B, and C and to publish a general description of these shocks with some examples.

5) Those National Committees, who have conducted research on the structure of the earth's crust, are requcsted to send their reports to the President of the commission before November 1, 1960.

6) Those National Committees, who have made measurements of ice thicknesses in the Antarctic, are requested to send their reports (with the material) to Prof. Bullen, Department of Applied Mathematics, University of Sydney, Australia.

7) Prof. Rothé, 38, Boulevard d'Anvers, Strasbourg, asks authors of papers and articles in seismology, published on the occasion of the IGY, to send to him reprints of these papers, so that a seismological bibliography of the IGY can be prepared.

8) The commission recommends to the International Committee of Geophysics that the gravimetric maps of the Arctic and the Antarctic are made in the same scale as the seismicity maps and may be published together in the volume "Seismology".

9) The commission decides to prolong its existence until the results of the IGY — and of the Int. Geophys. Cooperation 1959 — have been published.

10) The commission recommends the work of the World Data Centers to be continued. However, the sending of data on microseisms ("agitation microséismique d'origine météorologique") will be stopped.

Report of the Committee on the Publication of Microseismic Data

A committee consisting of *Hodgson* (Chairman), *Stoneley, Wadati,* and *Zátopek* met to consider how data on microseisms should be treated in the Annals of the I.G.Y. In the view of this Committee the vast amount of data collected cannot be analysed in time for publication or indeed for many years. It is recommended that the introductory chapter in the Annals should discuss the scheme on which data were collected, and refer the reader to the World Data Centres; and that the individual chapters should list those studies already made, and should encourage regional studies by interested seismologists of the data available in the W.D.C. The financial arrangements under which these data from the W.D.C. are available to research workers should be examined by the Union.

In the view of the Committee the world-wide collection of microseismic data carried out during the I.G.Y. and the I.G.C. should be stopped and should not be re-started until present data have been analysed. If individual seismologists require co-operation for limited periods or from a limited number of stations for particular studies they should arrange this on a personal basis.

The Committee suggests that a continuing Commission of the Association, consisting of seismologists with research interest in microseisms, should be set up to advise on future policy. This Commission might well include scientists from other disciplines.

The following delegates are elected members of the Committee on Microseisms : *Båth, Darbyshire, Donn, Jensen, Monakhov, Rykunov, Stoneley, Wadati, Zátopek.*

The recommendations are approved by the Association.

13. — Report of Nomination Committee. Election of Bureau and Executive Committee.

The recommendations of the Nomination Committee (see 7th Session, section 7) are unanimously adopted by the Association, i. e. *Prof. Byerly* is elected President of the Association, and *Prof. Pekeris* and *Prof. Savarensky* Vice Presidents. *Prof. Rothé* and *Dr. Båth* are re-elected as Secretary General and Associate Secretary General respectively.

The following delegates are elected as members of the Executive Committee : *Prof. Hales, Prof. Hiller, Sir Harold Jeffreys, Prof. Lomnitz, Prof. Wadati,* and *Prof. Zátopek.*

14. — Report of Finance Committee.

Prof. Byerly reports on behalf of the Finance Committee (*Ing. Bonelli-Rubio, Prof. Byerly, Dr. Hodgson;* see 7th Session, section 4) that the accounts of the Association for the period 1957-1960 have been examined and no objection found. The accounts are approved by the Association.

15. — Report of Publication Committee.

Dr. Stoneley reads the recommendation of the Publication Committee (*Dr. Båth, Prof. Karus, Prof. Rothé,* and *Dr. Stoneley*; see 7th Session, section 9):

1) The Comptes Rendus should be made more concise when practicable. The list of national committees should be omitted from the next volume, and published in full, say, once every three triennial (9 years). Corretions can be added if necessary.

The accounts of the Association and of the I.S.S. should be retained; they occupy only a few pages.

Communications that will be published elsewhere should be indicated by title only, with reference when available.

Reports of discussions on papers should be abbreviated at the discretion of the editors. For the present it will be advantageous to publish full summaries in French or English of papers that have been published (or will be published) in Russian.

2) The next two volumes of the Travaux Scientifiques should be devoted to reports of the two symposia

(i) The Crust of the Oceans and the Continents

(ii) The Propagation of Seismic Waves.

The manuscripts must be in the hands of the General Secretary by 1st November, 1960. The General Secretary undertakes to publish these reports as soon as possible, and at the latest by 1st July, 1961. He is empowed to ask authors, if necessary, to revise and shorten their communications. Each symposium will constitute a single volume of the Travaux Scientifiques, and these volumes will be on sale at booksellers.

The recommendations are approved by the Association.

Prof. Beloussov draws attention to the new rules for symposia as recommended by the Executive Committee of the Union. Following them, it would be possible to publish more than two symposia.

16. — Report of the Committee for the I.S.S.

Dr. Stoneley, Chairman of the Committee and Hon. Director of the ISS, reads the report (see also 7th Session, section 5):

Two long sessions of the Committee were held, at the first of which the Secretary General of the Union was present. The others attending were Prof. Bullen, Dr. Hodgson, Mr. Hughes (by invitation), Sir H. Jeffreys, Mr. Murphy, Dr. Kondorskaya, Prof. Rothé, Dr. Stoneley, Prof. Wadati, and Dr. Willmore.

Discussion took place under two main headings:

(1) the reduction of observations from 1960 August 1 onwards,

(2) the reduction of data from 1953 — 60 inclusive.

Under (1), Mr. Murphy informed the Committee that the determination of epicentres by electronic computer using the data from same 50 high-grade stations, was actually beginning on Mon. Aug. 1, 1960 under the aegis of the U. S. Coast and Geodetic Survey. How much information could be published about each earthquake remained for later decision. Additional work, such as fault-plane studies, under this programme, might need support from other nations, or from international sources.

Research on seismological problems, such as surface waves, magnitudes, energy, determinations of epicentres, etc. would be greatly facilitated by standardisation of instrumentation.

It became clear that the many ideas put forward would need further consideration by individual members, followed by a conference of the Committee in 1961. Provisionally a meeting in Cambridge, England, in early July, 1961, was agreed on, and the following resolution was unanimously adopted :

The Committee of the I.S.S. considers that the problem of the processing of seismic data has become so important and urgent that a conference of this Committee should be held during 1961 to consider (1) the general question of organisation and procedure ; (2) the details of the presentation and publication of seismological data. The Committee considers that, in virtue of the complexity of these problems, a conference of several days' duration will be necessary.

In order that preliminary plans for the conference might be available early in 1961 for submission to UNESCO, it was further agreed that, if desirable, a preliminary discussion might be held in Paris in January or February, 1961, at which the Secretary General of the Union and such members as could be present could consider the first draft of the proposals, which it had been agreed, should be the subject of memoranda sent by members of the Committee to the Chairman before the end of 1960.

Under (2) plans for expediting the compilation of the I.S.S. were tentatively agreed upon. These included the limitation to earthquakes of magnitude about 6, submission of data in standard form, the delegation of the reduction of small shocks to regional or national groups (e. g. Japan, U.S.S.R., European Seismological Commission) and the engagement of extra staff if accommodation at Kew can be provided.

It has later been decided to have a meeting on the reorganization of the ISS in Paris in 1961, July 10-13.

Dr. Batisse (UNESCO): The UNESCO General Conference meets in *November 1960* and votes the 61-62 programme and budget. It will at *that time* (and even before) be necessary to put forward the proposal and have it supported by national delegations to the General Conference. There will be no need to go into much technical details, but the proposal should be clear, so that the present meeting should perhaps immediately indicate their views. — The actual details could come later once the *principle* of UNESCO's support has been agreed by our Conference.

The report of the Committee of the ISS is adopted by the Association.

17. — Report on magnitudes.

Prof. Richter gives the report of the Committee on Magnitudes (Chairman : *Prof. Richter,* Members : *Dr. Båth, Ing. Kárník, Dr. Oliver, Dr. Shebalin)*:

1. A general standard of magnitude must be capable of quick application, without many special corrections and without long calculation. For shallow shocks, the best such standard is the magnitude *M*, based on the vectorially combined horizontal amplitude of surface waves with periods near 20 seconds. The constant term characteristic of each station should be determined by systematic investigation. Magnitudes determined by other methods should be related to the standard.

2. Magnitudes determined from body waves, using Gutenberg's charts and tables or in other ways, may be stated in terms of the *m* scale. If magnitudes determined from body waves are reduced to the surface wave (*M*) scale, the result should be separated from that given for surface waves alone.

3. Each reporting station or organization should publish with its bulletins a detailed statement of methods used to determine magnitude, with references to publications elsewhere if necessary. The methods should be illustrated by specific numerical examples showing how the observed amplitudes and periods are used.

4. Except in telegraphic reports, assignments of magnitude should be accompanied by statement of the amplitudes and periods on which they are based.

5. An international commission should be appointed to standardize the determination and reporting of magnitudes especially for deep-focus earthquakes. Definitions and procedures should be based so far as possible on the observed data, with a minimum of theory. Standardization must be accomplished without dogmatism, realizing that the study of magnitude and of its relation to energy are still completely open fields for investigation.

The report is adopted by the Association and a more permanent Committee on Magnitudes is elected with the following members : *Båth, Kárník, Mrs. Kondorskaya, Peterschmitt, Richter, Shebalin, Tsuboi, Wadati,* and *Zátopek.*

18. — The "Mohole project".

Dr. Maxwell reads the following report on the "Mohole project" :

At the Eleventh General Assembly of the International Union of Geodesy and Geophysics held in Toronto in September of 1957, a resolution was introduced by the U. S. representatives as follows :

> "Considering that the composition of the Earth's mantle below the Mohorovičić Discontinuity is one of the most important unsolved problems of geophysics ; and that, although seismic, gravity and magnetic observations have given significant indications of the nature of this material, actual samples that could be examined petrographically, physically, and chemically are essential ; and that modern techniques of drilling deep wells are rapidly developing to the point where drilling a hole 10 to 15 km deep on an oceanic island may well be feasible ; and that the crustal material above the Mohorovičić Discontinuity is also of prime interest, the IUGG urges the nations of the world and especially those ex-

perienced in deep drilling to study the feasibility and cost of an attempt to drill to the Mohorovičić Discontinuity at a place where it approaches the surface."

Since the adoption of this resolution, the American Miscellaneous Society was established chaired by Mr. Gordon G. Lill to investigate the feasibility of drilling a hole through the crust to obtain a sample of the Earth's mantle. The following report represents the progress of this Committee to date.

The Committee has established a Site Selection Panel to determine the most likely area to undertake drilling to the Mohorovičić Discontinuity. Using all available geophysical information, the Panel has decided the two areas which appear to be most feasible for this project are : (1) approximately 200 miles north of Puerto Rico in the Atlantic, and (2) about 100 miles southeast of Guadalupe in the Pacific. It is obvious that many more detailed seismic, gravimetric, magnetic, and bathymetric observations are required before a definite site can be selected.

In the spring of 1959, a four-ship expedition participated in the geophysical exploration of the area north of Puerto Rico. These ships were from the Lamont Geological Observatory, Hudson Laboratories of the Columbia University, Woods Hole Oceanographic Institution, and the Agricultural & Mechanical College of Texas. The joint expedition was carried out under the leadership of Dr. John Nafe of the Lamont Observatory. Detailed results of the expedition were reported at a joint scientific session of the International Association of Physical Oceanography and the International Association of Seismology and Physics of the Earth's Interior by Drs. Nafe and Drake. A second expedition has been made by members of the Committee in cooperation with the Scripps Institution of Oceanography, in the area southeast of Guadalupe. Island. These measurements concentrated on seismic reflections in the sediment, topographic work and deep current measurements. This detailed work was made in anticipation of a preliminary drilling test in the area.

In addition, the Committee has established a Panel on Scientific Objectives. This Panel has concerned itself not only with the types of measurements that are desirable and that will be made during the course of the drilling, but also with the problem of how the measurements should be made. One objective of this project will be to obtain as nearly as possible, a continuous core sample throughout the entire depth of the Hole. This core sample will be preserved for future work. Examples of some of the measurements that will be made on the core samples are seismic velocities, electrical and thermal conductivity, radioactivity, plus many other physical properties of the sediment and rock. In addition, the Hole will be continuously logged utilizing oilwell logging equipment adapted for the occasion.

A Third Panel on Drilling Techniques has been established. This Panel, assisted by the engineering staff of the Committee plus technical representatives from the various oilwell industries, has made a careful examination of the problem of deep drilling at sea. They have considered such problems as mooring, position keeping at sea, casings, drilling fluids, Magnus effects on the rotation of the drilling stem in water, turbo drills, special bits, coring devices, etc. These studies have been pursued from both theoretical and experimental standpoints. The results have shown that drilling in deep water, from a floating platform at the surface is a feasible procedure. They have also shown that a number of engineering difficulties will be present that cannot be solved without actual drilling tests at sea.

The future plans of the Committee include as a first step, an engineering test of drilling techniques in deep water. In conjunction with this, a scientific program will be organized to obtain maximum information from the sediment samples retrieved. This engineering test will probably be conducted during January of 1961. It will utilize the existing CUSS I drilling barge, suitably modified to drill in 12,000 feet of water. The barge will not be anchored and will be maintained above the drill hole by a system of propulsion units working in conjunction with a series of moored buoys. Essentially, three tests will be attempted during this operation.

(1) The drill stem will be jetted into the bottom to test the ability of initial penetration, weight problems, roll of the ship, maintaining position of the drilling barge, and other problems of handling the drill stem.

(2) A punch core will be made to the maximum depth possible to check out sampling techniques and to ascertain some of the physical properties of the soft sediments.

(3) A Hole will be drilled using rotary drills to the maximum length of the pipe available (approximately) or until the bit is worn out. This endeavor will provide a test for a specially designed bit and core barrel that will collect a continuous core in both soft and hard sediments. After maximum depth of the Hole is attained, the bit will be blown off the end of the drill stem, and pulled back to a point near the sediment surface. The drill stem will then be utilized as a casing to permit logging of the Hole with scientific equipment.

Should these preliminary attempts prove successful, additional holes will be drilled as time permits. The second step of the plans are dependent upon the success of the foregoing tests. If these tests are successful, the results will provide the engineering information needed for the design of a new barge, or the modification of an existing barge, which will be capable of drilling the deep hole to the Mohorovičić Discontinuity (MOHO).

The report is adopted by the Association.

Prof. Bullen : It has been reported in Australia that the U.S.S.R. is either contemplating or carrying out preliminary work on a Mohole project east of Kamchatka. Is any member of the Soviet delegation in a position to give any positive (or negative) statement on this subject ?

Prof. Beloussov : To my knowledge, no such experiments have been made. With reference to the upper mantle project (section 19 below) it is probable that similar work may be conducted by the U.S.S.R.

19. — The "Upper mantle project".

Prof. Beloussov reads the following report (Union Cir 10042 (AG) 30-7-60 (120); see also the 7th Session, section 8 :

The Executive Committee of the Union recognizes the importance of Union sponsorship of special research projects. As a first step the Executive Committee endorses the project "The Upper Mantle and its Influence on the Development of the Earth's Crust".

The Executive Committee approves the report of the Upper Mantle Ad Hoc Committee and recommends the implementation of this report.

The Executive Committee appoints as an organizing committee the following :

Prof. Beloussov (Chairman)
Prof. Ewing
Prof. Rittmann
Prof. Magnitsky
Prof. Heezen
Prof. Press
Prof. Tsuboi
Prof. Runcorn
Prof. Riznichenko.

The organizing committee shall circulate its preliminary report to all National Committees under a request for comments and offers of participation, to be received in January 1961.

The organizing committee shall meet in the spring of 1961 to prepare a final program of investigation and a plan for international participation.

Upper Mantle Project

We are all familiar with the success of special research projects which have the support of investigators from different countries. Our Union provides us with an excellent opportunity to identify problems worthy of special attention and to stimulate an international effort towards their solutions. This could well be one of the most important functions of the Union in future years.

We should like to propose as a first project for sponsorship by IUGG "The Upper Mantle and its influence on the developments of the Earth's crust". This problem is fundamental to the solution of the outstanding question of geology and solid Earth geophysics. It will require contributions and support from the Associations of Seismology, Volcanology, Oceanography and Geomagnetism. Although we are concerned only with the scientific aspects it should be recognized that this research effort offers the possibility of progress in exploiting mineral and energy sources of the Earth.

The following projects may be included :

1. Deep drilling : This includes drilling to the Moho in the deep sea and drilling to shallower depths under oceans, continents and islands for the purpose of studying deep sea sediments and intermediate layers of the crust.

2. Special development of deep sea seismographs for the purpose of exploring the upper mantle under oceans. Use of explosions and earthquakes as seismic sources to study upper mantle.

3. Distribution of arrays and networks of long-period seismographs to study upper mantle by means of surface waves. This method and preceding one would be particularly useful to explore the tectonic significance of the low-velocity zone in the upper mantle.

4. Special studies of deep-focus earthquakes to find mechanism of strain release in upper mantle.

5. Magnetic and gravimetric studies to explore variations in upper mantle with particular attention to mechanism and level of isostatic compensation. Development of geophysical methods to find deep magma chambers.

6. Studies of tectonic and magmatic development of crust. This includes field and laboratory studies. More detailed investigations of composition of crust and mantle in different tectonic zones are envisaged. Some examples are :

a. differentiation and selective smelting in the upper mantle,
b. the volcanic foci and their evolution,
c. the development of magmatic processes,
d. metamorphism as a factor of deep tectonics,
e. the constitution of the upper mantle in the different tectonic zones of the continents and oceans,
f. the tectonic and magmatic development of the crust and its relation to the processes in the upper mantle including the origin of the mid-oceanic ridges,
g. recent movements of the crust and the alteration of the different geophysical fields in time.

7. Theoretical studies of phase changes, thermal conditions, equation of state and processes of differentiation and movement. Special efforts to increase number of heat flow measurements in oceanic and continental crust. Magmatological studies.

8. High pressure laboratory studies of behavior of rocks. Geochemical studies of rocks and meteorites.

Prof. Bullen : I thoroughly agree with the importance of Prof. Beloussov's proposal. But I would not like to see it have the effect of reducing the energy put into problems of the deeper interior of the Earth.

Prof. Ewing : I strongly support the Upper Mantle Project. We have seen during this meeting that many parts of the program proposed are already being advanced rapidly. If we can give a little more in future to work on this program, we may expect that many of the outstanding problems will have been solved three years hence, when we next meet. I do not think that the funds required will be large enough to detract seriously from the support of other projects.

Prof. Byerly : In answer to Prof. Bullen's concern I think that larger funds for subcrustal research will be followed automatically by more funds for crustal research. If financial sources become enthusiastic about the one they will also be concerned with the latter.

Prof. Egyed : It seems to me that the importance of the crust in tectonical phenomena has been overestimated. Actually the upper mantle, down to about 800 km depth, seems to me to bear the explanation of all tectonical phenomena observed on the surface of the Earth. Therefore I should like to emphasize the importance of this research project.

Prof. Riznichenko : The discussion in this session has shown that the investigation of the upper mantle, combined with investigations of the Earth's crust, plays a significant role in our modern scientific life. A lot of separate reports presented here have a direct relation to this problem. I am sure that this project is worth being supported by our Association, taking into account its outstanding scientific and practical significance.

Mr. Dorman : The points listed under the upper mantle recommendations deserve strong support, since understanding these questions is the key to understanding the deformation and the materials of the crust.

The report, as presented by Prof. Beloussov, is adopted by the Association. At the final session of the Council of the IUGG a resolutions was adopted, covering the various points in the report, given by Prof. Beloussov.

20. — Discussion of resolutions to be presented to the IUGG.

The texts of the resolutions are given in Appendix 1 both in French and in English.

Resolution 1 (Tsunamis). A preparatory meeting for organizing a committee for basic research and warning of tsunami was held on August 1, 1960, in the University of Helsinki. *Mr. Murphy* reads the following report from this meeting :

Attendants : Leonard M. Murphy, U.S. Coast & Geodetic Survey
Robert A. Earle, do.
Lindsay P. Disney, do.
Sergei L. Soloviev, Conseil de Séism. Académie NAUK
Doak C. Cox, Hawaii Inst. of Geophysics, Honolulu
Kiyoo Wadati, Japanese Meteorological Agency
Ryutaro Takahasi, Earthquake Research Institute, Tokyo University
Cinna Lomnitz, Institute of Geophysics, Santiago.

Mr. Murphy took the chairmanship. Discussions were made about three items :

1) Seismological stations and reports,

2) Tide-gauge stations and reports,

3) Basic research.

Relative merits of two kinds of refraction diagrams — station-centered and origin-centered — were discussed. It was decided Japan, Chile, U.S.A. and U.S.S.R. will make refraction diagrams assuming tsunami origins at several tsunami-frequented regions along their coasts, and send them to U.S. Coast & Geodetic Survey, Geophysics Division, for the purpose of finding the best one for the practical use. Both kinds of refraction diagrams were recommended.

As to the seismological stations, following stations are desired to join the reporting net-work : Hongkong, Matsushiro, Santiago, Brisbane and a station in U.S.S.R. In the course of discussing seismological stations, use of WMO communications was considered desirable.

As to the tide-gauge stations, followings were recommended to join the reporting net-work : Tokyo, Osaka, Easter Island, Tahiti, Acapulco, and a station in New Zealand.

It was decided to limit the basic research to tsunami. Following scientists were recommended as tentative members of the research group :

Dr. Walter Munk, Scripps Institution of Oceanography
Dr. W. G. Van Dorn, do.
Dr. E. F. Savarensky, Inst. Physique du Globe, USSR.
Mr. L. P. Disney, US Coast & Geodetic Survey
Mr. L. M. Murphy, do.
Mr. D. C. Cox, Hawaii Institute of Geophysics
Dr. R. Takahasi, Earthquake Research Institute, Tokyo Univ.
Dr. C. Lomnitz, Institute of Geophysics, Santiago.

Dr. Takahasi was recommended as tentative chairman of the research group. Members will report their work at the Xth Pacific Congress to be held in Hawaii on Aug. 20-26, 1961.

Making draft of the resolution or recommendation for organizing this committee was left to Dr. K. Wadati.

Mr. Murphy then reads the proposed resolution (Resolution 1 in Appendix 1).

Prof. Bullen asks if there is already a network or only a few stations for observation and warning of tsunamis.

Mr. Murphy : About 20 stations exist, but more stations are asked for, especially in the South Pacific Ocean.

Prof. Bullen expresses his interest for stations in Australia.

Both the report and the resolution, as read by Mr. Murphy, are adopted by the Association.

Resolution 2 (Equipment of seismograph stations in South America).

Prof. Lomnitz presents the proposal. The resolution is adopted by the Association.

The session is closed at 16.30.

25th SESSION

THURSDAY, AUGUST 4 (afternoon)

Program

1.— Scientific communications : Recent Movements of the Earth's Crust ; cont.

148. — *M. Odlanicki-Poczobutt :* On the determination of land uplift by relevelling.

149. — *J. Niewiarowski* and *T. Wyrzykowski :* Détermination des mouvements contemporains verticaux de l'écorce terrestre sur l'étendue de la Pologne par la méthode de la répétition des nivellements de précision.

150. — *G. A. Zhelnin :* Present-day vertical movements of the Earth's surface in the north-western European part of the USSR.

151. — *M. I. Sinyagina :* The study of present-day vertical movements of the Earth's crust on the territory of USSR.

152. — *J. A. Mescherikov :* Recent movements of the Earth's crust in the north-west of the European part of USSR in the light of geological and geomorphological data.

153. — *V. K. Gudelis :* Recent vertical movements of the Earth's crust and the morphology of the sea-coast of the eastern Baltic area.

154. — *M. S. Uspensky :* Eine Untersuchung der Stabilität von geodätischen Zentren und Höhenmarken.

155. — *J. B. Small :* Settlement studies by means of precision levelling.

The session is held together with IAG. It is opened at 15.00 under the chairmanship of *Prof. Tsuboi.* The proceedings as presented here are not complete (summaries and references are missing), but more complete accounts may be found in the publications of IAG.

1. — Scientific communications : Recent Movements of the Earth's Crust (cont.).

148. — *M. Odlanicki-Poczobutt :* On the determination of land uplift by relevelling.

149. — *Dr. Niewiarowski* presents the paper by *J. Niewiarowski* and *T. Wyrzykowski :* Détermination des mouvements contemporains verticaux de l'écorce terrestre sur l'étendue de la Pologne par la méthode de la répétition des nivellements de précision.

Dr. Niewiarowski says in reply to a question by *Dr. Arnold,* that any possible correlation between the movements and gravity has not been studied.

150. — *Dr. Mescherikov* reads the paper by *G. A. Zhelnin :* Present-day vertical movements of the Earth's surface in the north-western part of the USSR.

Dr. Mescherikov says in reply to a question by *Dr. Lagrula,* that Dr. Zhelnin did not investigate relationships between gravity anomalies and crustal movements.

Mr. Myers : What is the reason for the closed area of negative movement in southeastern Esthonia beyond the apparent limit of regional positive movement.

Dr. Mescherikov : This region of subsidence apparently coincides with the negative block of platform basement.

151. — *Dr. Mescherikov* reads the paper by *M. I. Sinyagina :* The study of present-day vertical movements of the Earth's crust on the territory of USSR.

Prof. Tsuboi : 1) Is there any relation between topography and the reported movement ? — 2) Are there any lines that have been surveyed twice ?

Dr. Mescherikov : 1) It is possible to speak about a predominance of straight correlation between morphostructural elements and the signs of crustal movements. However, such a relationship is not universal. — 2) There are some lines surveyed three times. They show in the majority of cases a good agreement between signs of movement.

Mr. Myers : Has the illustration displayed by the speaker and entitled "Secular movement of the European part of the USSR" been published ?

Dr. Mescherikov : This map was published in the *Transactions of the Scientific Research Institute of Geodesy, Air Survey and Cartography,* Moscow, No. 123, 1958.

Dr. de Graaff-Hunter : I understand that the interesting results presented are based on values of tidal stations in the Gulf of Finland and the Black Sea. In view of the recent comparisons of the levelling in western Europe with values of geoidal level given by numerous tidal stations, it would be extremely interesting if connexion could be made also with the tidal stations used in the investigation presented here.

Prof. Shneiderov : 1) What is the resultant of the uplift minus the subsidence in the area you have investigated and in areas investigated by other authors ? — 2) What is such a resultant for the Earth's surface as a whole ? Are such data available ? — 3) Are there investigations in the Soviet Union on determination of an absolute value of such a resultant uplift or subsidence ?

Dr. Mescherikov : 1) The data obtained by Dr. Sinyagina and Dr. Zhelnin were used. There is good agreement between them. — 2) and 3) There is no material for elucidating these problems so far.

152. — *Dr. Mescherikov* then gives his own paper : Recent movements of the Earth's crust in the north-west of the European part of USSR in the light of geological and geomorphological data.

Dr. Lagrula : Is there any seismicity in the zones between subsidence and uplift ?

Dr. Mescherikov : New data collected by Dr. Andreev (*Izv. Akad. Nauk SSSR, Ser. Geofiz.*, No. 12, 1956, pp. 1484-1487) show that the Russian platform is not fully deprived of seismic phenomena. The epicenters of weak earthquakes in this area mostly coincide with the transitional belts between regions of upheaval and subsidence.

153. — *Dr. Mescherikov* reads the paper by *V. K. Gudelis :* Recent vertical movements of the Earth's crust and the morphology of the sea-coast of the eastern Baltic area.

Dr. Collette objects against the idea of Dr. Gudelis that the crustal wave which appeared to be moving to the center of the depression might be of elastic character. Instead this is exactly the kind of behaviour which might be expected from a plastic mantle.

154. — *M. S. Uspensky :* Eine Untersuchung der Stabilität von geodätischen Zentren und Höhenmarken.

155. — *J. B. Small :* Settlement studies by means of precision levelling.

The session is closed.

26th SESSION

FRIDAY, AUGUST 5 (morning)

Program

1. — Scientific communications : Recent Movements of the Earth's Crust ; cont.

156. — *C. A. Whitten :* Horizontal movement in the Earth's crust.

157. — *S. Miyamura :* Recent and present crustal movements in Japan.

158. — *C. Lomnitz :* Crustal deformations associated with recent Chilean earthquakes.

159. — *J. A. Mescherikov :* Proposal for establishing an international organisation for studying recent movements of the Earth's crust.

The session is held together with IAG and is opened at 10.40 under the chairmanship of *Prof. Tsuboi.*

1. — Scientific communications : Recent Movements of the Earth's Crust (cont.).

156. — *Mr. Whitten* gives his paper : Horizontal movement in the Earth's crust.

The conventional method for determining horizontal movement in the Earth's crust has been to reobserve networks of triangulation and compare the coordinates of the adjusted results. A new method of analysis of reobservations is presented. The changes in the angles in a network indicate the presence of strain or deformation within the crust. This type of analysis will also indicate small displacements which may occur along fault lines in an area of seismic activity. Results of the application of this technique to resurveys along the San Andreas Fault in California are given in graphical form.

The paper has been published in the *Journal of Geophysical Research,* Vol. 65, No. 9, 1960, pp. 2839-2844.

Mr. Eiby : In the cases described as 'continuous slip', as distinct from 'elastic rebound', am I to take it that there are no detectable earthquakes at all ? Could there not be a multiplicity of very small shocks ? It is difficult to believe that relative movements of the sides of a fault can take place with no disturbance from roughnesses.

Prof. Byerly, in reply to Mr. Eiby : The movement is not continuous — there are quiet periods, then jerks, sometimes lasting for several days. These do not correlate with local earthquakes. In the region in question the fault has not experienced sudden large displacements in historic time.

Mr. von Huene : 1) What is the width of the deformed zone along the fault you have described ? — 2) Has the information presented been used to calculate such physical properties as the coefficient of friction along a fault and rigidity ?

Prof. Byerly, in reply : 1) About 10 miles (16 km). — 2) It has been used to infer lower rigidity along the fault.

Dr. Cook : Dr. Froome at the National Physical Laboratory is working on two methods which may enable distances of 100 m to 1 km to be measured to 1 in 10^6 — one involves the generation of microseisms of 1 mm wave length and the other the modulation of light at about 10'000 Mc/s. If these are successful, deformations of the Earth will be measurable at more frequent intervals than Mr. Whitten has used.

157. — *Prof. Miyamura* presents his paper : Recent and present crustal movements in Japan.

Quaternary crustal movements in Japan are especially active along two zones, namely Kurile Is.-Inner (or Japan Sea) side of NE Japan — Izu Is. — Marianne Is. *and* Outer (or Pacific) side of SW Japan. The crustal movements of the former zone are characterized by 1) the "basin forming'" movements, i. e. sinking of alluvial or diluvial plains and/or upheaval of surrounding basement mountains, the wave length of which is about several tens of kilometers in order, and 2) the "active folding" movements, i. e. upheaval of anticlines and sinking of synclines, with the wave length of the order of several kilometers. These two modes of movements were proceeding in the last two periods between the successive precise levellings in the same sense as the movements disclosed by geomorphological studies for the whole Quaternary. Of course, they were sometimes disturbed by the occurrence of destructive earthquakes (Nosiro).

In this zone we have many active volcanoes and the crustal movements around the volcanoes are also important items. Big alluvial plains indicate in several places in Japan extraordinary sinking which must be attributed to some artificial causes as pumping up of underground water or natural gas (Tokyo, Niigata, etc).

Crustal movements of the outer side of SW Japan are mainly considered in relation to the big earthquakes off the south coast and covered a wide area in simple mode of inclination. They were made clear both by the geomorphological studies and repeated precise levellings. The sense of the movements was not the same in different periods.

Besides, we have several kinds of interesting mode of crustal movements, e. g. block movements in inner Japan (Tango district), local uplift in earthquake swarm epicentral region (Wakayama district), etc.

Recent and present crustal movements in Japan are treated from the view points of geology, geomorphology, and geophysics or geodesy in detail.

The full paper will be submitted for publication in *Revue de Géographie Physique et de Géologie Dynamique.*

158. — *Prof. Lomnitz* presents his paper : Crustal deformations associated with recent Chilean earthquakes.

No summary or reference is available.

159. — *Dr. Mescherikov* presents his proposal : Proposal for establishing an international organisation for studying recent movements of the Earth's crust.

No summary or reference is available.

The session is closed.

27th SESSION

FRIDAY, AUGUST 5 (morning)

Program

1. — Scientific communications : Internal Constitution of the Earth.

160. — *F. A. Vening Meinesz :* Arguments in favour of mantle convection currents.

161. — *J. Dorman, M. Ewing,* and *J. Oliver:* Structure of the upper mantle from surface wave dispersion.

162. — *K. Aki* and *F. Press :* Upper mantle structure under oceans and continents from mantle Rayleigh waves.

163. — *M. Landisman, Y. Satô,* and *M. Ewing :* Shear wave velocities in the upper mantle.

164. — *I. Lehmann :* S and the structure of the upper mantle.

165. — *L. M. Balakina, H. I. Shirokova,* and *A. V. Vvedenskaya :* Double refraction in anisotropic layers and some peculiarities of the low-velocity layer in the Earth's mantle.

166. — *V. A. Magnitsky, N. V. Kondorskaya, V. V. Khorosheva,* and *V. N. Zharkov :* The wave guide in the mantle of the Earth and its probable physical nature.

167. — *L. Egyed :* A new theory on the origin of the Earth.

168. — *L. Egyed :* The development of the Earth and the origin of the Gutenberg channel.

169. — *L. Egyed :* The Dirac-Gilbert equation and the mechanism of expansion.

170. — *D. C. Tozer :* The structure of the transition region of the mantle.

171. — *B. P. Belikov :* Elastic properties of rocks.

172. — *J. H. Mathews :* Solid state calculations by W. C. Overton, Jr., indicating high electrical conductivity in the core.

The session is opened at 9.05 under the chairmanship of *Prof. Beloussov.*

1. — Scientific communications : Internal Constitution of the Earth.

160. — *Prof. Vening Meinesz* gives his paper : Arguments in favour of mantle convection currents.

1. The pattern and structure of island arcs strongly point to uniaxial horizontal compression in the crust, and this is difficult to explain otherwise than by a mantle current of great dimension exerting a drag on the crust.

2. The relative movements of the crustal blocks on both sides of the arcs (shear movement, or compressive movements by crustal down-buckling, or both together) amount to several tens of kilometers or more and this is too much to be accounted for by the contraction theory while mantle currents can easily explain them. The same argument is provided by the continued shear movement along crustal fault-planes, as e.g. the San Andreas fault in California and the Great Glen fault through Scotland ; these movements continue through long periods and the total relative displacements may amount to more than a hundred kilometers.

3. The fact that in the same period crustal compression occurs in geosynclines and crustal tension in graben areas, as e.g. the Upper and Lower Rhine graben areas and the Great Lakes area in East Africa, as well as shear movements as mentioned above, is impossible to account for by the contraction hypothesis, but simple by the convection-current hypothesis.

4. The regression during the first part of an orogenic period and the transgression afterwards can be easily explained by the presence of convection currents in the mantle and not by the contraction theory. As Griggs first has mentioned, the convection current throughout the whole mantle thickness only makes about half a turn and, as the temperature conduction is extremely small, it practically does not affect the phenomenon during the half turn which lasts some 50-100 million years. We can therefore assume that the current carries its temperature along with it and also the corresponding density changes. During the first quarter of a revolution the current must have brought the high temperature and corresponding low density of the lower mantle layer in the rising current, which in general occurs under the continent and causes the crust above it, therefore, to rise, while the lower temperature matter of the upper part of the mantle is carried along in the subsiding current and makes the crust on top of it subside.

5. The polar shifts, which geomagnetic data force us to admit, cannot be accounted for by shifts of the rotation axis of the earth. As, however, the drag-forces exerted by the system of mantle convection on the crust may be expected to have a resulting moment, we can understand that this moment rotates the crust around the earth and thus makes it shift with regard to the poles.

6. The results of the spherical harmonic development of the earth's topography above and below sea-level, first made by Prey in 1922 up to the 16th order and recently repeated in the Netherlands up to the 31st order, show a strong correlation with the distribution which mantle currents may be expected to adopt. (1)

7. The results of the comparison of the spherical harmonic development of the land topography and of the sea-floor topography show remarkable features which can be explained by mantle convection currents that in the beginning of the earth's history had the character of currents in a viscous matter and since assumed the character of currents in crystalline matter. (2)

8. Bowen's theory about the origin of basalt — he assumes that pressure relief causes selective fusion of peridotite, giving basaltic magma and olivine, the latter remaining in the solid state — gives another argument in favour of convection currents : the selective fusion of peridotite in the upper layer of the mantle must soon have made this layer barren of basaltic constituents, but we know that the formation of basalt must have continued throughout the whole earth's history. Convection currents in the mantle can provide an explanation ; they continued to bring new peridotite to the surface, thus producing new basaltic magma.

9. The origin of the deep basins inside island arcs, as e.g. the Banda basin, which came into being during a fairly recent period, is difficult to explain without admitting convection currents in the upper part of the mantle, which, therefore, must have had a smaller scale than the currents hitherto discussed.

Before leaving the subject of the mantle convection hypothesis, it must be mentioned, that the gradual increase of density between the depths of 500-900 km, which is much more than what can be explained by the direct effect of the increase of pressure, does not constitute an objection to assuming convection throughout the whole mantle. In a paper under the title : « On the olivine-spinel transition in the earth's mantle » (3), Dr. J. L. Meijering and Dr. C. J. M. Rooymans of the Philips Physics Laboratories at Eindhoven, Netherlands, show that phase changes and possibly also chemical changes may account for the density transition in the layer mentioned without preventing convection currents to pass through this layer.

References :

(1) F. A. Vening Meinesz : The results of the development of the earth's topography in spherical harmonics up to the 31st order ; provisional conclusions, *Proc. Kon. Nederl. Akad. v. Wetensch.*, Ser. B, 62, 2, Amsterdam 1959.

(2) F. A. Vening Meinesz : Continental and ocean-floor topography ; mantle convection currents, *Proc. Kon. Nederl. Akad. v. Wetensch.*, Ser. B, 63, Amsterdam 1960.

(3) *Proc. Kon. Nederl. Akad. v. Wetensch.*, Ser. B, 61, 5, Amsterdam 1958.

Prof. Shneiderov : I want to note that by assuming a model of the expanding Earth one can arrive at an apparent current on the surface of the mantle. These "currents" are actually a dilatation of the mantle, on which the continents and islands float. The magma of the upper mantle should flow from under the continents and islands, expanding the continents at a rate lower than the expansion (tangential) of the surface of the mantle ; the islands should have a still lower rate of dilatation because of the insufficient area of the bottom of the islands for the magma to have a good grip to extend the islands. The expansion hypothesis is capable of explaining many of the phenomena brought about by Prof. Vening Meinesz, including orogenesis. The mechanism I propose seems much simpler compared with that of the mantle current theory. It was noted in papers by other authors that the "surges" of currents in the mantle should occur with quiet intervals of long period, perhaps billion of years, which objection has not yet been adequately answered.

Prof. Bullen : What is the order of the period of one equivalent full cycle in the envisaged convective motion ?

Prof. Vening Meinesz : I think, as Griggs has first mentioned, that the current makes only half a turn, bringing the cooled (and therefore heavier) mantle part down and the warm (and therefore lighter) mantle part up. Then a period of rest ensues, during which the first part looses its heat towards the outside and the second part is heated up by the adjacent core. Then again the mantle is unstable and, if a secondary cause is present for causing the mantle to overcome its elastic strength limit, it makes again half a turn. These half-turn mantle currents cause the periods of orogeny in the crust.

Prof. Goguel : Je suis d'accord avec l'ensemble des considérations qui ont été exposées aujourd'hui par le Prof. Vening Meinesz. Mais je voudrais souligner que si on admet, avec lui, que le manteau est cristallin, on doit s'attendre à des processus élémentaires non linéaires ; par exemple, la dissipation d'énergie dans une zone à fort gradient de vitesse peut élever la température et réduire la viscosité : la forme du courant ne serait alors plus décrite par une fonction harmonique. Tout au moins en deuxième approximation, il sera nécessaire de tenir compte de cette possibilité.

Prof. Vening Meinesz : Je suis tout à fait d'accord avec les remarques faites par M. Goguel, mais je ne crois pas que ces phénomènes changent le caractère principal du cycle.

Dr. Båth asks if the Earth's rotation (Coriolis force) will permit such a simple circulation as a single loop over a depth interval of as much as nearly 2900 km.

Prof. Vening Meinesz emphasizes the low velocity of the currents, but admits that the question is well justified. There are so far no observations to answer this question definitely.

Prof. Coulomb : Comment le Prof. Vening Meinesz voit-il le mouvement à trois dimensions dans les cellules de convection ? Montée de la matière dans une cellule et descente dans les cellules voisines ? Ou montée au centre d'une cellule et descente au bord, comme dans les expériences de laboratoire ? Ou encore l'inverse ?

Prof. Vening Meinesz : Je crois que les cellules ont une grande dimension verticalement au plan du mouvement circulaire ; la distribution des cellules a le caractère des harmoniques sphériques de Legendre. Cela correspond au caractère linéaire des géosynclinaux et des chaînes de montagnes associées. Ce caractère n'était pas là au commencement de l'histoire terrestre quand les courants dans le manteau étaient encore du type de courants dans un liquide visqueux. Pendant ces périodes les boucliers se formaient, qui ne sont pas linéaires.

The Chairman, *Prof. Beloussov,* expresses his admiration of Prof. Vening Meinesz' research works.

161. — *Mr. Dorman* reads the paper by *J. Dorman, M. Ewing,* and *J. Oliver :* Structure of the upper mantle from surface wave dispersion.

In 1954 Ewing and Press showed that trains of long-period waves on seismograms of great earthquakes were Rayleigh waves, the dispersion of which depends on the properties of the mantle. Waves of frequencies now commonly observed on recently-developed seismographs potentially contain information on elastic properties down to depths of 400 to 800 km in the earth. However, until the use of electronic digital computers, the recovery of this information from the recorded data was accomplished only in rough approximation because of the difficult numerical problem of computing the exact dispersion curve for a mantle with arbitrary distribution of elastic parameters. The multi-layer method used by the present authors quickly gives accurate and reliable numerical results and gives us a new tool of investigations.

Dispersion data for Rayleigh waves of periods less than 100 sec indicate a shear velocity of 4.6 to 4.7 km/sec below the M, consistent with results from explosion seismology. The shape of the dispersion curve between about 60 and 225 sec gives evidence for a strong decrease in shear velocity beginning at depths immediately below the M or slightly deeper. The data are consistent with the previous results of Gutenberg and of Lehmann that a minimum shear velocity of 4.3 to 4.4 km/sec exists between 100 and 200 km depth. The strong positive gradient of shear velocity below 200 km is primarily responsible for the minimum of group velocity of Rayleigh waves at about 225 sec.

In the sub-oceanic upper mantle which was not previously as well known from body wave studies as was the sub-continental mantle, the use of long-period surface waves has yielded significant new results. Consistent with results obtained from Love waves by Landisman and others, Rayleigh waves indicate that the low-velocity region of the upper mantle extends upward to much shallower depths beneath the ocean than beneath the continents. Rayleigh wave dispersion data reported by Sutton and others for paths on the Pacific basin are interpreted to indicate that shear velocity below the M decrease to about 4.3 km/sec at depth of about 60 km and that shear velocities are somewhat lower than in the sub-continental mantle down to about 400 km. Thus Rayleigh wave evidence indicates deep regional difference in the upper mantle which must be considered in connection with the history and structure of continents and ocean basins.

The paper has appeared in *Bull. Seism. Soc. Amer.*, Vol. 50, No. 1, 1960, pp. 87-115.

Prof. Bullen : Do I infer that the S velocity distribution shown in the curve C of the last slide is well compatible with Mr. Dorman's wave dispersion results ? I ask the question because some of my recent work on P waves (not yet concluded) indicates that a P velocity distribution similar in form to the curve C is compatible with up-to-date travel-time data. Other models, however, appear, so far as I have yet gone, to be also possible.

Mr. Dorman : Curve C, which is a shear velocity distribution for the upper mantle of the oceans derived from Love wave dispersion by Landisman and others, is in reasonably good agreement with Rayleigh wave dispersion data. The exact positions of the layer interfaces in the layered model do not have a great effect on the computed dispersion curve. However, the general shape of the distribution is important. The general shape of curve C is similar to that of curve B which is the layered solution derived from oceanic Rayleigh wave data.

Prof. Press : It is a pity that Prof. Gutenberg is not here to see the substantiation of the mantle low-velocity layer which he believed in with very few supporters (Dr. Båth among them). This paper places the existence of the Gutenberg layer beyond doubt.

Dr. F. S. Grant asks for effects of the curvature of the Earth.

Mr. Dorman : Preliminary considerations indicate that although curvature does have a fairly strong effect at the longer periods on phase velocity, the net effect on group velocity is not likely to be such that the main conclusions of this paper will be seriously affected. No set of calculations based on the spherical layered model has been undertaken.

162. — *Dr. Aki* gives the paper by *K. Aki* and *F. Press :* Upper mantle structure under oceans and continents from mantle Rayleigh waves.

Theoretical seismograms of Rayleigh waves based on several models of mantle structure are compared with actual records for various paths. It is found that model 8099 of Dorman, Ewing, and Oliver explains seismograms for Pacific paths but does not agree with records from Indian-Atlantic ocean paths in the period range shorter than about 80 sec.

The velocity of the Airy phase corresponding to the group velocity maximum is significantly lower for the Indian-Atlantic path than for the Pacific. A new model will be presented to account for this.

The paper will appear in the *Geophysical Journal.*

Mr. Brune : All interpretations of group velocity alone involve an ambiguity in constant of integration. Hence there is an infinite continuum of phase velocity curves which are associated with each group velocity curve. Although Dorman case 8099 yields an approximately correct oceanic group velocity curve, the phase velocity for this case is not correct by the order of 3 per cent in the period range around 120 sec. To make proper interpretation of mantle structure we must have more direct measurements of phase velocity.

Dr. Aki : I agree with you that more direct measurements of phase velocity are necessary. In a separate paper "The use of long-period surface waves in the study of earthquake mechanism" (21st Session, paper 126), I have used the phase velocity curve for 8099 in the period range 40-150 sec extensively to obtain source functions. I obtained also the radiation pattern of source functions for a few earthquakes from the IGY records. The result suggests that 8099 is a good model at least for this frequency range.

163. — *Dr. Landisman* gives the paper by *M. Landisman, Y. Satô,* and *M. Ewing :* Shear wave velocities in the upper mantle.

Machine calculations have been applied to various cases of Love wave dispersion in elastic media having gradients in their physical properties. Among the cases considered are several which are directly related to the structure of the earth.

Models having two homogeneous layers over a gradient half-space were used to study the structure of the upper mantle under continents and oceans. The study of dispersion in these models has produced results which have since been confirmed by Dorman and others.

These results include :

1. Under continents a zone of low shear velocities exists between depths of roughly 100 and 200 km.
2. The upper mantle beneath the oceans is different from that under the continents. Under oceans the region of low shear velocities rises to depths of about 50 km. The low-velocity zone is thicker, and the velocities are lower, than under continents.

The complete paper is in preparation for publication.

164.— Dr. Willmore reads the paper by *I. Lehmann :* S and the structure of the upper mantle.

The Northeastern American S_d is clearly recorded up to about 14° and the time-distance points fit approximately a straight line of slope 24.0 sec/degree. At 14° the S_d line breaks off and at greater distances the S phase is delayed. Correspondingly the S velocity can be taken to increase slightly from the Mohorovičić discontinuity down to 120-150 km and to decrease there. At about 220 km depth the velocity as well as the velocity gradient will increase abruptly.

It was found that European S_d phases, propagating with a velocity practically the same as the Northeastern American S_d could be distinguished and that a velocity distribution similar to the one assumed for Northeastern America could be adopted. However, the European S_d is often quite weak or missing and a later phase is read for it. It was found that this later phase could be interpreted as a reflection on, or a refraction in the discontinuity surface at depth of about 220 km.

S travel times from a focus 130 km deep were calculated on the above assumptions and they were found to be in fair agreement with the observations from some Rumanian shocks having a common focus at this depth.

The paper is published in the *Geophysical Journal,* Vol. 4, 1961 ("Special Harold Jeffreys Volume").

The chairmanship is handed over to *Prof. Vening Meinesz.*

165.— Mrs. Dr. Vvedenskaya presents the paper by *L. M. Balakina, H. I. Shirokova,* and *A. V. Vvedenskaya :* Double refraction in anisotropic layers and some peculiarities of the low-velocity layer in the Earth's mantle.

The observations of the displacement field of the longitudinal and transverse (SV and SH) waves propagating in the Earth's mantle show increasing amplitudes of P and SV waves relative to SH waves, if the lowest points of the rays are situated in the depth intervals 250-500, 900-1000, 1200-1300, 1800 and about 2200 km.

This phenomenon can be connected with polarization of the transverse waves in aeolotropic layers corresponding to the depths mentioned.

The properties of the medium show symmetry relative to an axis coinciding with the vertical direction.

The relation between elastic constants of the medium in aeolotropic layers is determined on the basis of the plotted curves for the amplitude ratio of P, SV, and SH waves.

Apparently the aeolotropy of the medium is artificial and was evoked by the effect of the additional loads.

Studies of the low-velocity layer showed that this layer begins in the depth interval 60-100 km and reaches the depth 200 km at least, and has sharp boundaries.

The complete paper will appear in *Publications du Bureau Central Séismologique International, Sér. A, Trav. Sci., Fasc. No. 21.* In addition, the paper has been published in parts in Russian as follows :

1) Vvedenskaya, A. V. : On displacement field for the rupture of the continuity of the elastic medium, *Izvestiya AN SSSR, Ser. Geophys.*, N4, 1959, pp. 516-526.

2) Shirokova, H. I. : Some data on velocity variation character in upper layers of the Earth's mantle, *Izvestiya AN SSSR, Ser. Geophys.*, N8, 1959, pp. 1127-1137.

3) Vvedenskaya, A. V., Balakina, L. M. : Double refraction in the Earth's mantle, *Izvestiya AN SSSR, Ser. Geophys.*, N8, 1959, pp. 1138-1146.

166. — *Prof. Magnitsky* presents the paper by *V. A. Magnitsky, N. V. Kondorskaya, V. V. Khorosheva,* and *V. N. Zharkov :* The wave guide in the mantle of the Earth and its probable physical nature.

1. Records on seismograph stations in USSR confirm the existence of P_a and S_a phases on seismograms not corresponding to any known or supposed phase of common waves.

2. The travel-time curves of Pa and Sa phases are straight lines :

$$t_{Pa} = 0{,}9558 + 0{,}2205\ \Delta^{\circ}$$
$$t_{Sa} = 0{,}3780 + 0{,}4180\ \Delta^{\circ}$$

t_{Pa}, t_{Sa} and Δ being in minutes and degrees respectively.

3. These waves are apparently propagated through the wave guide (the channel) in the upper parts of the mantle. Their velocities are as follows :

$$V_{Pa} = 8{,}2 \text{ km/sec}$$
$$V_{Sa} = 4{,}5 \text{ km/sec}$$

4. It is supposed that emergence of Pa wave from channel is due to scattering on inhomogeneities as well as to transformation into SV wave. Emergence of Sa wave from channel is probably due only to scattering.

5. The physical cause of the wave guide cannot be established definitely. Most reasonable causes of formation of the low-velocity layer in the mantle are as follows : great thermal gradient, polymorphic transition, amorphysation. Quantitative data are in sufficient agreement with calculations based on all the above-mentioned hypotheses.

A paper with the same title by V. A. Magnitsky and V. V. Khorosheva will be published as follows :

1) In Russian in *Dokl. Akad. Nauk SSSR,* 1960.

2) In English in *Annali di Geofisica,* Vol. 14, 1961, pp. 87-94.

167. — *Prof. Egyed* gives his first paper : A new theory on the origin of the Earth.

The regularities in the solar system suggest that the planets were formed out of the Sun. On the other hand, the principle of the conservation of angular momentum postulates that they could not be formed out of the Sun except if a decrease of the gravity coefficient is assumed. Consequently, the only way out of this contradiction is opened by the Dirac equation.

The author demonstrates that the development of the solar system, as well as its essential features, may be derived from Dirac's equation.

Reference :

L. Egyed : Dirac's Cosmology and the origin of the Solar System, *Nature,* No. *4725,* pp. 621-622, 1960.

168. — *Prof. Egyed* continues with his second paper : The development of the Earth and the origin of the Gutenberg channel.

The author proves that the Dirac-Gilbert equation serving as a basis for the expansion theory has the consequence that the Earth's mantle must be, excepting the uppermost 200 kilometres, similar in constitution to a magma of intermediary composition rich in volatiles. An ultrabasic composition characterizes exclusively the volatile-poor shells situated immediately beneath the acidic crust.

Density does not increase monotonously with depth : on the contrary, after a local maximum between 50 and 100 kilometres, it has a slight local minimum. Consequently, the Gutenberg channel is due to changes in material composition rather than to thermal effects. The hydrosphere and most of the atmosphere must have come to exist simultaneously with the crust, in the first phases of the Earth's life. The evolution of the surface of the Moon is in a close parallelism with the evolution of the Earth's mantle.

Reference :

L. Egyed : On the origin and constitution of the upper part of the Earth Mantle, *Geologische Rundschau,* Vol. 60, 1960 (In print).

169. — *Prof. Egyed* finishes with his third paper : The Dirac-Gilbert equation and the mechanism of expansion.

According to a result arrived at previously by the author, the radius of the Earth increases yearly by 0,4 to 0,8 millimetres. The mechanism of expansion consists in that the outer and inner core undergo an alteration tending from a high-pressure modification of matter towards a lower-pressure one. However, this alteration is possible only if the pressure is steadily decreasing on the critical surface of transition. This is solely warranted by the Dirac equation which states that the gravity coefficient varies inversely as a time parameter, $f = \varkappa / t$. Gilbert has shown that this equation may be derived by reasonable assumptions from the general theory of relativity, and that the present-day value of t amounts to $4.1.\ 10^9$ years. The author shows that by the Dirac-Gilbert equation as well as by Bullen's data, the minimum value of expansion amounts to 0.3 millimetres annually, in accordance with observations.

Reference :

L. Egyed and L. Stegena : Physical background of a dynamical Earth model, *Zeitschrift f. Geophysik,* Vol. 24, 1959, pp. 108-115.

L. Egyed : The expansion of the Earth in connection with its origin and evolution, *Geophysica,* Helsinki, Vol. 7, No. 1, 1959, pp. 13-22.

Prof. Hast questions the possibility of the Earth's expansion, considering the fact that very large horizontal stresses (about 500 kg/cm² at 500 m depth) have been found in Scandinavia (see 22nd Session, paper 136).

Prof. Egyed compares his model with a rubber band, which is stretched and as a consequence contracts crosswise.

Prof. Hast replies that very large horizontal stresses exist also in other parts of the world, and there are indications that these are a general phenomenon on the globe.

170. — *Dr. Tozer* presents his paper : The structure of the transition region of the mantle.

On a affirmé dans cette communication que le manteau consiste en olivine et la couche de transition entre 400 et 900 km de profondeur est due à une transformation de la structure de ce composé vers une structure de spinelle. On a affirmé que les composants de l'olivine forment les solutions solides idéales dans les deux phases. Avec ces affirmations on peut établir les conditions d'équilibre de phase à chaque température, pression et composition moyenne.

Pour déterminer les conditions d'équilibre existant aux diverses profondeurs on doit connaître la composition et les distributions de température et de pression dans le manteau. On connaît la distribution de pression avec une précision considérable d'après Bullen et d'autres, mais on connaît avec moins de précision la distribution de température et pour faire les calculs on affirme que les conditions adiabatiques existent pour toutes les profondeurs. Cela correspond à une situation dans laquelle le flux de chaleur dans le manteau est porté entièrement par les courants de convection.

Puis, il est possible de calculer un certain nombre de grandeurs physiques dans la couche de transition en utilisant pour la transition les valeurs déterminées par l'expérience et quelques résultats séismiques dans le manteau.

Les variations de densité, température et constantes élastiques dans la couche de transition pour diverses compositions du manteau sont indiquées et les densités sont comparées aux valeurs de Bullen.

La chaleur latente de changement d'état est mise en jeu seulement dans le domaine de température dans lequel coexistent les deux phases. Dans le domaine de transformation, il est possible de considérer l'énergie calorifique mise en jeu comme une chaleur spécifique globale, composée de la somme des chaleurs spécifiques des deux phases et d'un terme représentant la chaleur latente de changement d'état. Cela réduit aussi la diffusivité de la chaleur, et l'effet de cette réduction sur les solutions de l'équation de conduction de la chaleur est discutée brièvement.

171.— Prof. Riznichenko reads the paper by *B. P. Belikov :* Elastic properties of rocks.

1. The knowledge of elastic constants is necessary for geophysics, geology, mining and building industries.

2. In the laboratory of the Institute for the Geology of Ore Deposits, Mineralogy, Petrography and Geochemistry of the USSR Academy of Sciences determinations were made mostly by static methods, by computing E and σ on the basis of deformations under compression, measured by electric tensionmeters of resistance and Martens device. An error in the experiment of 1 % represented a sufficient precision, considering a certain heterogeneity of the rocks, which results in a fluctuation of physical properties up to 10 %.

3. Stress-strain diagrams indicated, that a direct dependence is characteristic only for a few rock types, possessing low porosity. The majority of rocks does not follow Hooke's law, producing concave curves for longitudinal deformations (higher E under a greater load) and hysteresis loops. Porous rocks are characterized by residual deformations, which disappear under the second and subsequent loads and return again after a rest.

4. A comparison with constants determined by a dynamic method (effected by an ultrasound seismoscope IKL-4 at the Institute of the Earth's Physics, researcher O. I. Silaeva) gave a satisfactory coincidence of E values under pressures of 0.3 strength. Under small pressures up to 100 kg/cm² dynamic moduli are much higher than the static ones. During dynamic tests Poisson ratios (σ) proved to be too low.

5. Tables of constants, compiled according to IGEM laboratory data, contain characteristics of over 300 fresh rocks, collected into petrographic groups. In addition to elastic constants they give porosity, density, strength constants, hardness. Because of the presence of residual deformations under the first load, the tables give two values of Young modulus : E_1 — "coefficient of deformation" calculated for

the entire deformation and E — modulus of elasticity, computed for the elastic deformation only. E is always larger than E_1, but in rocks with a low porosity their values can coincide.

6. Elasticity values of rocks depend upon elastic constants of the minerals of which the rocks consist and for monomineral imporous rocks they can be calculated by corresponding crystallographic equations. Thus for quasi-isotropic aggregates of calcite and quartz we get by computation the following isothermic constants :

E for calcite $= 12.09 \,.\, 10^5$ kg/cm^2 ; $\sigma = 0.43$

E for quartz $= 10.32 \,.\, 10^5$ kg/cm^2 ; $\sigma = 0.06$,

i. e. the modulus of elasticity for quartz is lower than the modulus of elasticity for calcite. This is confirmed by actual rocks : massive marbles give E up to $10.0 \,.\, 10^5$ kg/cm^2, σ up to 0.40 ; quartzites E up to $9.17 \,.\, 10^5$ kg/cm^2, $\sigma = 0.09$. Poisson ratios for all quartz rocks (quartzites, sandstones) are very low, about 0.10.

For silicate polymineral rocks similar computations are still impossible, owing to the difficulties in determining elastic constants for the main rockforming minerals, which belong to the triclinic and monoclinic systems. Here it is possible to form a judgment about the influence of the mineral composition from the elastic constants of different groups of intrusive rocks with a low porosity. The highest modulus up to $17.0 \,.\, 10^5$ kg/cm^2 is obtained for certain ultrabasic rocks, basic rocks give about $10.0 \,.\, 10^5$ kg/cm^2 and granites about $6.5 \,.\, 10^5$ kg/cm^2. In the last case, we have, apparently, the influence of quartz and mica ; acid feldspars have a lower E than basic feldspars.

7. An increase in porosity sharply decreases the elasticity modulus and damps the influence of the mineral composition, which is especially noticeable in groups of effusive and sedimentary rocks.

8. The influence of structure is less obvious — it reflects through a change in porosity.

9. For Paleozoic limestones of the Russian platform mantle the average porosity amounts to 15.6 per cent, the average modulus E is $3.7 \,.\, 10^5$ kg/cm^2; for limestones in geosynclines (Caucasus, Middle Asia) porosity is 0.90 per cent, and E is $7.7 \,.\, 10^5$ kg/cm^2. Porosity is here a function of the geological history.

10. Studies of elastic properties are carried out in the USSR also in the Institute of the Earth's Physics of the USSR Academy of Sciences (Y. V. Riznichenko, M. P. Volarovich, O. I. Silaeva, P. G. Shamina) and in industrial institutes.

The paper has been submitted for publication in *Acta Geophysica et Geodaetica,* Prague.

The chairmanship is handed over to *Prof. Goguel.*

172. — *Dr. Mathews* gives his paper : Solid state calculations by W. C. Overton, Jr., indicating high electrical conductivity in the core.

No summary or reference is available.

Mr. von Herzen : Has there been a theoretical consideration of the effects of other elements existing in the core, such as nickel and silicon ?

Dr. Mathews : No. This paper has only considered pure iron.

The session is closed at 12.35.

28th SESSION

FRIDAY, AUGUST 5 (afternoon)

Program

1. — Scientific communications : Internal Constitution of the Earth ; cont.

173. — *W. A. Heiskanen :* Report on isostasy.

174. — *B. K. Balavadze* and *G. S. Shengelaia :* Structure of the Earth's crust of the Greater Caucasus from gravity data.

175. — *R. M. Demenitskaya :* To the question of determination of the thickness of the Earth's crust, using gravimetric, topographic, and bathymetric data.

176. — *G. Sutton :* Gravity observations along the Western Rift Valley of Africa.

177. — *A. L. Hales* and *D. I. Gough :* The isostatic anomaly field in South Africa.

178. — *E. N. Lyustikh :* The energy of gravitational differentiation of the Earth's mantle.

179. — *B. I. Levin* and *S. V. Majeva :* On the thermal history of the Earth.

180. — *H. A. Lubimova :* On the processes of heat transfer in the Earth's mantle.

181. — *L. Knopoff :* The temperature in the interior of the Earth from a semi-empirical quantum model.

182. — *G. D. Garland* and *D. H. Lennox :* Geothermal heat flow in western Canada.

183. — *H. A. Lubimova, G. N. Starikova, F. W. Firsov,* and *L. N. Lusova :* On the determination of the heat flow in some points of the USSR.

184. — *R. P. von Herzen :* Pacific Ocean floor heat flow measurements during IGY.

The session is held together with IAG and is opened at 14.30 under the chairmanship of *Prof. Goguel.*

1. — Scientific communications : Internal Constitution of the Earth (cont.).

173. — *Prof. Heiskanen* presents his Report on isostasy.

The report is published by IAG.

174. — *Prof. Balavadze* gives the paper by *B. K. Balavadze* and *G. S. Shengelaia :* Structure of the Earth's crust of the Greater Caucasus from gravity data.

1. The Greater Caucasus is a folded Alpine system stretching from the Black Sea to the Caspian. Study of the Earth's crust structure of this portion of the Alpine geosynclinal belt is of great interest from both the geophysical and the geological points of view, for it contributes to our knowledge of the regularities of the Earth's crustal evolution and to the problems connected with the theory of isostasy.

2. The study of the crustal structure of this particular mountain area is based on a fairly detailed chart of gravity anomalies according to the Bouguer reduction, compiled by us with due allowance for area-relief effects within a radius of 200 km., and for the deviation of geoid from spheroid. To obtain quantitative data characterizing the structure of the Earth's crust Δg curves were interpreted along twelve profiles directed as far as possible transversely to the path of isanomals and to the Main Caucasus Range. At the same time use has also been made of the results of layer-thickness determinations of the crust by seismic methods as well as of the results of geologic and density investigations.

A quantitative interpretation of Δg curves has been made with the assumption that the anomaly of gravity is due to the anomalous masses found chiefly within the three-layered Earth's crust.

3. The results of this interpretation are generalized in the form of isobath diagrams of granitic-layer surfaces (including pre-Mesozoic rocks), those of the basalt, and of the subcrustal material underlying the Greater Caucasus. It is to be seen from these diagrams that :

a) The surface of the granitic layer, which forms a crest along the Main Caucasus Range, has a depth of 4—6 km in the Novorossisk district; in the central portion of the Greater Caucasus it is exposed; and, farther east, it again sinks, reaching a depth of some 16 km under the Apsheron peninsula. In the northern foothill region and in the southern inter-mountain depression the granitic surface drops down to 5 to 10 km in a number of places.

b) The basaltic surface presents, in the main, a mirror-image reflection of the granitic, i. e. in the central part of the range it drops down to a depth of 30 km, and in the eastern and western parts it rises to 20 km in the Novorossisk region, and to 24 km in that of Baku.

c) The surface of the subcrustal material, in the main, duplicates the morphology of the basaltic. In the central part of the range the depth of the bed is 56—64 km, and in the Novorossisk and Baku regions 43—45 km.

4) The Greater Caucasus as a whole, and especially its central part is immersed in the subcrustal material, thus forming a root which stretches along the whole extent of the Main Caucasus Range. To sum up : The Greater Caucasus is characterized by such structure as is peculiar to areas of recent folding.

The paper will appear in *Publications du Bureau Central Séismologique International, Sér. A, Trav. Sci., Fasc. No. 22.*

Prof. Balavadze says in reply to a question by *Dr. Collette* that the Greater Caucasus is to a great extent isostatically compensated. In reply to another question he further says that the gravimetric distribution of crustal thickness coincides with the seismic data, but the gravimetric study gives us an additional tool for establishing variations in the thickness and for revealing some details of the crustal structure in this region.

175.— The paper by *R.M. Demenitskaya :* To the question of determination of the thickness of the Earth's crust, using gravimetric, topographic, and bathymetric data, is presented.

No summary or reference is available.

176.— *Dr. Sutton* gives his paper : Gravity observations along the Western Rift Valley of Africa.

A gravimetric survey was conducted along the Western Rift Valley of Africa. The data include 392 gravity observations between latitudes 3° N and 7°5 N and between longitudes 28°E and 33°E. This area extends on both sides of the rift, from north of Lake Albert to about 130 km from the southern end of Lake Tanganyika. The gravity values are tied to the Duclaux-Martin African base network. The gravity anomalies obtained are used in conjunction with geological and seismological observations in the area to interpret the crustal structure of the region.

The paper has not yet been published.

Mr. Bestow : The slide shown of the Albert rift, in which the lake is shown as being comparatively shallow, may not be typical in that over a large part of the lake the depth is considerable, certainly going below sea level. It is known that at Butiaba, about half way up the east shore of the lake, there is a considerable depth of sediment. These two factors may well be sufficient to account for the negative Bouguer anomalies.

Prof. Schleusener : Are the gravity points situated about the mean heights of the surroundings so that the "free air values" approximately represent the "mean free air values" of Puttnam, or had the stations as usual to be set at the deepest spots of the terrain, as the roads usually follow the valleys. In the latter case the representative "*mean* free air values" should be much higher.

Dr. Sutton : In most cases measurements were purposely taken where relatively flat areas surrounded the station for a considerable distance at about the average elevation. This was not always possible since most measurements were made along the roads.

177. — *A. L. Hales* and *D. I. Gough :* The isostatic anomaly field in South Africa.

Due to last minute changes this paper could unfortunately not be given at the session. An abstract and a reference is given here.

The paper describes the preparation of an isostatic anomaly map of South Africa. Estimates of crustal thickness are made by using the regression coefficient criterion proposed by Heiskanen, the minimum sum of squares criterion proposed by Bowie and a new criterion based on minimum sum of squares of departure from the regression lines. It is found that the regression coefficient criterion is not satisfactory because it is sensitive to systematic effects such as arise in South Africa near the escarpment. The other criteria yield results which are consistent with the seismically inferred crustal structure, i. e. with a crustal thickness 30—40 km.

Geophys. J. Roy. Astr. Soc., Vol. 2, No. 4, 1959, pp. 324-336, and Vol. 3, No. 2, 1960, pp. 225-236. See also a paper by A. L. Hales in the *Journal of Geophysical Research,* Vol. 65, No. 7, 1960, pp. 2155-2168.

178. — The paper by *E. N. Lyustikh :* The energy of gravitational differentiation of the Earth's mantle, is presented.

The Earth's crust consists mainly of acidic and basic rocks (sial). It may be believed that the crust has been forming owing to the differentiation of the mantle sial being lifted by the forces due to gravity. Some energy must release from this process. It would be interesting to prove whether the output of energy is enough to maintain the geotectonic activity.

All the values are given to within an order only.

Energy allowance

The volume of the crust	$V = 10^{25}$ cm^3
The duration of its formation	$t = 3{,}5 \,.\, 10^9$ years
The mean output of sial	$\bar{V} = \frac{V}{t} = 3.10^{15}$ cm^3/year
The mean depth, from where sial emerges	$H = 3{,}5 \,.\, 10^7$ cm
The density difference sima-sial	$D = 0.5$ g/cm^3
Gravity in the mantle	$g = 10^3$ gal
The mean output of energy	$e = Dg H\bar{V} = 5.10^{25}$ erg/year

The part of the mantle having lost some sial gets heavier and may plunge down to the bottom of the mantle. Such "chemical convection" would afford much more energy.

We have	$H = 2{,}5 \,.\, 10^8$ cm
for this, and therefore	$e = 4.10^{26}$ erg/year

We assume the geotectonical efficiency of the mechanism of differentiation in the range $1 > \beta > 0.01.$

Then the energy supply for tectonics T has the limits

$$10^{27} > T > 10^{23} \text{ erg/year}$$

Energy need

The mean energy of seismic waves z was $8{,}4 \cdot 10^{24}$ erg/year in 1896-1955 (B. Gutenberg, *Tr. AGU,* 37, nº 5, 1956). We assume for last $3{,}5.10^9$ years $10^{27} > z > 10^{23}$ erg/year.

The energy output in the foci Z may be somewhat greater : $10^{29} > Z > 10^{23}$ erg/year.

The energy of all the tectonic processes T may be 10 to 1000 times as great as Z : $10^{31} > T > 10^{24}$ erg/year.

Conclusion. The mechanism of differentiation can provide geotectonics with energy if the efficiency of this mechanism is high enough, and the required amount of energy is not too great.

The paper is published as follows :

1) In Russian in *Izv. Acad. Sci. USSR, Ser. Geofiz.*, No. 3, 1960, pp. 402-408.
2) In English in *Annali di Geofisica* (in press).

179. — The paper by *B. I. Levin* and *S. V. Majeva :* On the thermal history of the Earth, is presented.

The problem of the thermal history of the initially cold Earth heated by radioactivity is investigated in the O. Schmidt Institute of Physics of the Earth during last decade. Continuing this work the authors had made the calculations for several Earth models differing in the mean content of radioactive elements, in the specific heat of the interior and in the role of the radiative heat transfer. The formation of the Earth crust is regarded as a long enduring process which had started 3.10^9 years ago and continues till now.

The calculations permit the following conclusions :

1) When the role of radiative (or exciton) heat transfer is important the calculated and observed values of the radioactive elements content are less than that supposed in preceding calculations. This is in accordance with the recent analyses of radioactive elements in meteorites which give a less content than the earlier ones.

2) The conclusion that the outer layers of the mantle depleted in radioactive elements are cooling now, obtained by H. A. Lubimova for the case of instantaneous crust formation is not confirmed when the long enduring character of the crust formation is taken into account. For the linear increase of the radioactive elements content in the crust it is shown that the temperature of superior mantle layers remains almost constant and the temperature at the Mohorovičić discontinuity seems to continue to increase. Accordingly the heat flow through the surface continues to increase (or has reached a broad maximum).

3) The comparison of calculated values of the heat flow for the parts of the Earth with continental and oceanic crust has shown that their difference is considerably less than the difference in the crust thickness. It is also because the heat originates not only from the crust but from the deeper layers too. This agrees with the observational evidence that no considerable systematic differences exist between the heat flow on the continents and on the oceans.

The paper is published as follows :

1) In Russian in *Izv. Acad. Sci. USSR, Ser. Geofiz.*, No. 2, 1960, pp. 243-252.
2) In English in *Annali di Geofisica* (in press).

180. — *Mrs. Dr. Lubimova* gives her paper : On the processes of heat transfer in the Earth's mantle.

1. Apart from the ordinary molecular thermal conductivity there may be the radiative transfer as well as heat transfer by excitons — excited states of the atoms — at high temperature in the Earth's mantle. Existence of excitons in the olivine mantle is confirmed by spectral data on the infrared absorption of olivine. The comparative contribution of each of these thermal processes varies with the depth. The ordinary, so-called, lattice conductivity predominates up to the depth of about hundred km. Further the radiative transfer of heat begins to prevail. But its intensity should decrease at large depth, because of the increase of the absorption coefficient. In the lower part of the mantle the main contribution to the thermal conductivity seems to be explained by the exciton component. The complete thermal conductivity has its minimum value in the upper layers of the mantle. The temperature gradient rises in this region. This explains the decrease of the seismic velocities in the low-velocity layer.

2. The variation of the activation energy for the electron intrinsic conductivity with temperature and pressure is considered. This allows to explain the observed electroconductivity in the lower part of the Earth's mantle and to compare it with the data on the temperature of the interior.

3. It seems hardly possible that the convective currents are existing till now. If they have existed, the heat losses should have surpassed several times the observed heat flow. It seems that the uninterrupting convection in the past cannot cause the transition from the secular heating to the cooling of the interior because of the existence of the poor-conducting upper layer, preventing the heat losses.

The paper will be published in the *Journal of the Physics of the Earth*, Tokyo, No. 1, 1961, and in *Annali di Geofisica*, Vol. 14, 1961, pp. 65-78. It has appeared in Russian in *Trudy instituta fiz. zemli*, No. 11 (178), 1960.

Mr. von Herzen : Is it possible by any physical or geophysical measurements to distinguish at the present time between your model of Earth temperatures and that of Prof. Verhoogen (*Trans. Amer. Geophys. Union*, Vol. 32, 1951, pp. 41-44 ; Vol. 35, 1954, pp. 85-92 ; Vol. 36, 1955, pp. 866-874)?

Mrs. Dr. Lubimova : It is very difficult at the present time.

181. — *Prof. Knopoff* presents his paper : The temperature in the interior of the Earth from a semi-empirical quantum model.

A semi-empirical equation of state of a solid at absolute zero is presented that depends only upon two parameters. This equation is rigorously asymptotic to the Thomas-Fermi quantum model at high pressures. It is shown to be an excellent fit to the high pressure experiments of Altschuler et al. in the case of iron and several other metals.

From the model, the rate of change of compressibility with pressure can be calculated at absolute zero. For the assumed composition of the interior of the Earth, the difference of the rate of change of compressibility as calculated from the model and from the Bullen (or similar) data for the Earth's interior can only correspond to terms due to temperatures different from absolute zero. The temperature in the Earth's interior is thus dependent on the difference between the actual and the absolute zero compressibility gradient. The coefficient in this relation depends upon a knowledge of Gruneisen's constant and the thermal coefficient of expansion. The former is relatively simple to estimate.

The thermal coefficient can be estimated from the values of the thermal coefficient of expansion at extremely high pressures obtained from the quantum model. A semi-empirical equation for the thermal coefficient is presented that is similar to the pressure-density equation of state outlined above. This permits the calculation of the temperature in the Earth's interior with the use of only a small number of parameters.

The paper will probably be published in the *Journal of Geophysical Research.*

182. — *Dr. Garland* gives the paper by *G. D. Garland* and *D. H. Lennox :* Geothermal heat flow in western Canada.

La mesure du flux de chaleur provenant de la terre dans le bassin sédimentaire de l'ouest canadien a été effectuée par l'Université de l'Alberta. Les gradients ont été déterminés dans le kilomètre supérieur d'anciens trous de sondage stériles, quelques-uns étaient vieux de 13 ans et la conductivité de carottes-échantillons a été mesurée au moyen d'un appareil à barre divisée.

Dans la partie centrale de l'Alberta le flux thermique est en moyenne de 1.5 microcalorie par cm^2.sec. ; et il a été établi par des mesures individuelles que le flux varie suivant la nature lithologique de la roche ignée qui constitue la couche sous-jacente à une profondeur d'environ 3 milles, et qu'il est légèrement supérieur dans les régions granitiques. A Norman Wells, lat. 65°30' N, le flux de chaleur montre un excédent de 2.5 microcalorie par cm^2.sec.

The paper will appear in the *Geophysical Journal.*

Prof. Goguel : Je m'étonne que vous citiez la valeur élevée du flux à Resolute Bay. Je pensais qu'il avait été établi que le gradient thermique élevé mesuré dans le sondage tenait au voisinage de la baie, sous laquelle n'existe pas de permafrost, et qui donne lieu à un flux latéral de chaleur.

Mr. S. P. Clark, Jr. : Lachembruch has inferred that most of the heat flow at Resolute Bay originates in the difference between temperatures on land and on the sea floor. Can a similar explanation of the high value at Norman Wells be found ?

Dr. Garland : The only body of water near Norman Wells is the MacKenzie River, 0.3 km from the well in which temperatures were measured. The contribution to the measured flow from this body is estimated to be less than 6 per cent.

183. — *Mrs. Dr. Lubimova* reads the paper by *H. A. Lubimova, G. N. Starikova, F. W. Firsov,* and *L. N. Lusova :* On the determination of the heat flow in some points of the USSR.

The results of the temperature gradient measurements in deep boreholes and the thermal conductivity measurements of rocks are described. These measurements have been made on the bases and with the method of apparature, developed by the geothermic group of the Institute of the Earth's Physics. The influence of the deviations from the stationary thermal regime of the borehole on the temperature measurement is evaluated.

The thermometer of the resistance type allows to measure temperatures up to 250-300°C at a pressure up to 600 atmospheres and gives a precision of 0.01°C. This method dissects the boundaries of the different rocks distinctly.

The method of the measurement of the thermal constants of rocks is based upon the principle of the instant linear heat source. The non-ideality of the conditions of the experiment is taken into account for the calculated formulae.

The temperature measurements were made for 20 boreholes at depths from 400 to 2600 m in the regions of the Stavropol, Krasnodar, and Poltava provinces. The heat flow was determined for the Black Sea region of the Krasnodar province. Correlations of the data with geotectonical and hydrogeological conditions of the regions have been demonstrated.

Reference is made to a paper by H. A. Lubimova, G. N. Starikova, F. W. Firsov, L. N. Lusova, and A. P. Shushpanov : Determination of surface heat flow in old Mazesta (USSR), published in Russian in *Izv. Acad. Sci. USSR, Ser. Geofiz.*, No. 12, 1960, and in English in *Annali di Geofisica* (in press).

184. — *Mr. von Herzen* gives his paper : Pacific Ocean floor heat flow measurements during IGY.

Geophysicists are interested in the rate of the heat outflow through the earth's surface as a clue to the composition and dynamic processes of the earth's interior and as an indication of the earth's past history. During the past ten years, heat flow measurements have been made in the Pacific and Atlantic Ocean areas, as described in Bullard et al. (1956). A measurement is made by separate determinations of the temperature gradient and thermal conductivity in the upper few meters of ocean floor sediments. The present study extends the original 25 measurements in the Pacific to a total of 74, with emphasis on the variations of the heat flow with geographic location.

The measured values range from 8.09×10^{-6} to 0.14×10^{-6} cal/cm² sec, a ratio of more than 50 : 1. An areally weighted average of all values in the Pacific gives 1.66×10^{-6} cal/cm² sec, whereas the average of normal deep oceanic area values is 1.06 $\times 10^{-6}$ cal/cm^2 sec, comparing closely with the continental values. In the eastern Pacific a high heat flow band seems to be associated with the East Pacific Rise, with low heat flow indicated for a large area to the west, and also possibly to the east, of this Rise. The trenches bordering South and Central America also appear to be associated with low heat flow. The horizontal scale of the variations is several thousand kilometers, and the observed pattern may be indicative of a mantle convection cell of similar dimensions. Some relatively local variations in heat flow exist which have no apparent structural correlation.

A consideration of the possible sources of the observed heat flow points to mantle radioactivity with associated convection as perhaps the best explanation. Anomalous seismic refraction results on the East Pacific Rise are probably related to abnormally high heat flow. Oceanic crustal thickness appears to be relatively independent of heat flow variations, and isostatic compensation of the East Pacific Rise may be accomplished by thermal expansion of mantle rock. Gravity and magnetic field measurements at sea may be expected to show significant correlations with the heat flow values.

Reference : Bullard E. C., A. E. Maxwell and R. Revelle, Heat flow through the deep sea floor, *Advances in Geophysics,* Vol. 3, 1956, pp. 153-181.

Prof. Goguel : Si on construirait un histogramme de toutes les valeurs du flux, mesurées sur les continents (ou des gradients, ce qui reviendrait pratiquement au même), il serait coupé net vers 3 ou 4 microcal, à l'inverse de celui qui vient de nous être montré. — Ceci tient à ce qu'un gradient plus élevé signifierait qu'à une certaine profondeur la limite de vaporisation de l'eau serait atteinte, et la différence de densité entre eau et vapeur est telle, qu'en pareil cas il s'individualise nécessairement des courants ascendants de vapeur, par l'intermédiaire desquels se fait le transfert de chaleur, sans qu'il subsiste de stratification régulière des températures. — Mais ceci ne joue pas pour les gradients au fond des continents, la pression ne permettant en aucun cas de changement d'état de l'eau.

Dr. Rikitake : Recent observations of heat flow in Japan showed that heat flow values are not much different from the world's average in spite of seismic and volcanic activity there.

The session is closed.

29th SESSION

FRIDAY, AUGUST 5 (afternoon)

Program

1.— Scientific communications : Seismic Wave Propagation ; cont.

185.— S. Mueller : A comparison of theoretical and experimental surface wave dispersion curves.

186. — *J. Dorman:* Use of matrix methods in calculations relating to properties of surface waves.

187. — *J. Nafe* and *J. Brune :* Phase velocities of mantle Rayleigh waves.

188. — *Y. Satô, M. Landisman,* and *M. Ewing :* Love wave dispersion in a heterogeneous spherical Earth.

189. — *G. Sutton, M. Ewing,* and *M. Major :* Rayleigh-wave group-velocity extrema.

190. — *K. Aki* and *J. M. Nordquist :* Theoretical seismogram computation by electronic computer for mixed paths.

The session is opened at 14.40 under the chairmanship of *Dr. Lapwood.*

1. — Scientific communications : Seismic Wave Propagation.

185. — *Dr. Mueller* gives his paper : A comparison of theoretical and experimental surface wave dispersion curves.

Rayleigh wave data obtained previously by Fourier and transient analyses of seismic signals having travelled over oceanic paths were used to deduce a theoretical system transfer function describing the observed mode of wave propagation. The impulse response of this dispersive system has a striking similarity with actual seismograms of shocks from the Mid-Atlantic Ridge recorded at stations near the east coast of North America. An electrical system analogue representation can easily be realized which yields the same impulsive response in terms of Bessel functions of the first kind whose argument is proportional to time. Their order depends on a quantity proportional to distance. The asymptotic behaviour of these functions for large values of argument and order provides, in addition, a means for justifying the use of the "peak-and-trough" method of standard dispersion analysis. Finally the observed low-pass effect is examined in the light of experimental evidence.

The paper is expected to appear in the *Bull. Seism. Soc. Amer.*

186. — *Mr. Dorman* presents his paper : Use of matrix methods in calculations relating to properties of surface waves.

The concept of a matrix which represents the effect of a single stratum on the periodic motion of a stratified elastic medium was introduced into the field of seismic calculations by Haskell in 1953. It was shown that a product of matrices could provide a relation between motions at points in an arbitrarily stratified medium. The theory, originally applied to normal mode vibrations of the Rayleigh and Love types on a flat-layered solid earth, can be extended to take account of liquid portions of the geologic sections, spherical curvature, and the effect of gravity.

An important application is the derivation of a period equation for the normal modes of a stratified medium with a free surface. In the flat earth case one can obtain the relationship between period and phase velocity for waves of the Love or Rayleigh type by solution of a transcendental algebraic equation. In the spherical earth case the periods for free vibrations of the torsional or radial type of various orders can be found by solving a similar equation. The convenience and speed with which these problems can be solved in an electronic digital computer result from the simple iterative form of the equation. With modern computing machines numerical solutions of the period equations can be obtained for virtually any cases of geologic interest involving a stratified earth.

In other applications calculations of the amplitude distribution in normal modes, or the calculation of the response to arbitrary applied stresses or displacements are equally feasible.

Much of the material presented is published as follows :

1) J. Oliver and J. Dorman : Exploration of sub-oceanic structure by the use of seismic surface waves, *The Sea : Ideas and Observations,* Interscience, New York-London.

2) J. Dorman and D. Prentiss : Particle amplitude profiles for Rayleigh waves on a heterogeneous Earth, *Journal of Geophysical Research,* Vol. 65, No. 11, 1960, pp. 3805-3816.

187. — *Prof. Nafe* reads the paper by *J. Nafe* and *J. Brune :* Phase velocities of mantle Rayleigh waves.

Phase velocity as a function of period has been determined for Rayleigh waves in the period range 100-400 seconds. The results were derived from a study of seismograms from the southeastern Alaska earthquake of July 10, 1958 and from published data on the Assam earthquake of August 15, 1950. The method depends on measurement of the travel time of wave crests along an arc of known length with proper correction for change of period with distance. For observations of a single Rayleigh wave train at a single pair of observing stations crest identification is uncertain and so too is the resulting phase velocity period curve. A set of phase velocity curves may be computed, each one corresponding to a different choice of crest identification. Only one of these is consistent with the data from several earthquakes and several pairs of observing stations. In the present work, high precision in phase velocity measurement is achieved by using the observations of the Rayleigh waves R_3 and R_5 at Pasadena of the Assam earthquake. Data from the southeastern Alaska earthquake are used to resolve the ambiguity resulting from uncertainty in crest identification. The final phase velocity curve is estimated to be accurate to better than 1% in the range of periods 100 to 400 seconds.

The paper has appeared under the title "Observations of phase velocity for Rayleigh waves in the period range 100 to 400 seconds" in the *Bull. Seism. Soc. Amer.,* Vol. 50, No. 3, 1960, pp. 427-439.

188. — *Dr. Landisman* presents the paper by *Y. Satô, M. Landisman,* and *M. Ewing :* Love wave dispersion in a heterogeneous spherical Earth.

The equation of motion for Love waves in a heterogeneous spherical earth, with suitable boundary conditions, has been solved numerically, using the modified Adams method. This method of solution of the dispersion problem is similar to that previously described by Satô for surface wave dispersion in a heterogeneous flat earth.

The fundamental and several higher radial modes of vibration have been calculated for the Jeffreys-Bullen model, and also for one proposed by Miss I. Lehmann as a result of shear body-wave studies.

The paper presented has been published in two parts :

1) Part I : Theoretical periods for the fundamental and higher torsional modes, *Journal of Geophysical Research,* Vol. 65, No. 8, 1960, pp. 2395-2398.

2) Part II : Theoretical phase and group velocities, *Journal of Geophysical Research,* Vol. 65, No. 8, 1960, pp. 2399-2404.

189.— Dr. Sutton gives the paper by *G. Sutton, M. Ewing,* and *M. Major :* Rayleigh-wave group-velocity extrema.

Oceanic Rayleigh waves recorded at Suva, Fiji clearly exhibit the long periods associated with the inverse branch of the dispersion curve beyond the maximum of group velocity U_0, near 35 seconds period. Energy from the Airy phase associated with the maximum is evident on the seismograms more than one minute preceding the arrival time of U_0. The apparent velocity of the beginning of these waves depends upon epicentral distance and seismogram trace amplitude. If the apparently impulsive beginning is chosen as the arrival time of U_0 a velocity significantly higher than the proper value is obtained. A reconstruction of the Rayleigh waves, based upon the theory of the Airy phase near the maximum and the theory of the stationary phase for other times, reproduces the observed seismograms reliably. The reconstructions indicate that the amplitude factor (independent of distance), which depends upon conditions at the focus and the elastic structure of the wave guide, generally varies slowly with frequency. Comparison of waves traversing almost identical paths indicates strong effects on the frequency dependence of the amplitude factor produced by different source parameters.

Continental Rayleigh waves from Hudson Bay recorded at Palisades show a maximum at 8 seconds period and a minimum at 20 seconds. The seismograms, including the maximum and the minimum of group velocity, can be explained by the theory mentioned above. The minimum in group velocity near 230 seconds period in including periods on either side of the minimum has also been studied.

The paper has not been published.

Dr. Mueller : The effect of higher apparent velocities for onsets of the Airy phase by using higher instrumental magnification is in agreement with the results of the explicit approximation in terms of Bessel functions of the first kind given in my paper (paper 185) and is related to the uncertainty principle in frequency and time ("reciprocal spreading").

190.— Dr. Aki reads the paper by *K. Aki* and *J. M. Nordquist :* Theoretical seismogram computation by electronic computer for mixed paths.

A program was devised to compute theoretical seismograms of Rayleigh waves for a given epicenter and a given station entirely automatically on an electronic computer.

The earth's surface is divided into three regions; continents, Pacific Ocean, and oceans other than the Pacific. Allowance can be made for differences in structure in these regions. This simple division seems satisfactory at present for Rayleigh waves of periods longer than 35 sec.

The paper has been published in the *Bull. Seism. Soc. Amer.*, Vol. 51, No. 1, 1961, pp. 29-34.

The session is closed at 16.40.

APPENDIX I

RESOLUTIONS

Adopted by the Helsinki Assembly 1960

ASSOCIATION INTERNATIONALE DE SEISMOLOGIE
et de
PHYSIQUE DE L'INTERIEUR DE LA TERRE

RESOLUTIONS
(texte français)

RESOLUTION I

I. — *Résolution concernant l'étude des Raz de Marée (Tsunamis)*

L'U.G.G.I.,

Considérant

que de nombreuses pertes de vies humaines et des dégâts considérables sont causés par les tsunamis,

que les systèmes d'alertes organisés par l'observatoire magnétique d'Honolulu (U.S. Coast and Geodetic Survey), par le service météorologique japonais (Japan Meteorological Agency) et par le service météorologique de l'URSS ont déjà fonctionné avec succès sur le pourtour de l'Océan Pacifique en sauvant des vies humaines,

que le déclanchement des avis d'alertes est basé sur la connaissance du mécanisme de formation et de propagation des tsunamis,

Recommande

que les systèmes d'alertes actuellement en vigueur soient perfectionnés grâce à la collaboration de toutes les nations bordant l'Océan Pacifique,

qu'une coopération internationale groupant les diverses disciplines intéressées par l'étude des tsunamis soit stimulée par la création d'une commission composée de membres de l'A.S.P.I.T. et de l'A.I.O.P.,

que les données concernant les tsunamis soient rassemblées par les Centres A et B où elles pourront être mises à la disposition des chercheurs,

que l'US Coast and Geodetic Survey entreprenne la publication d'une bibliographie sur les tsunamis,

que la Commission Séismologique Européenne inscrive à son programme des recherches sur les raz de marée séismiques qui se produisent sur la côte atlantique de l'Europe (en particulier au Portugal), au Maroc et dans le bassin méditerranéen,

Exprime

sa reconnaissance à l'Organisation Météorologique Mondiale (O.M.M.) pour l'intérêt qu'elle montre dans ce domaine et assure l'O.M.M. de son désir sincère d'une étroite collaboration dans la poursuite de l'étude des tsunamis.

RESOLUTION II

II. — *Résolution concernant l'équipement des stations séismologiques en Amérique du Sud*

Prenant en considération le fait que les études séismologiques sont d'importance primordiale dans les régions séismiques d'Amérique du Sud et particulièrement en Bolivie, Chili, Colombie, Equateur et Pérou,

L'U.G.G.I. recommande que dans ces pays les recherches séismologiques soient stimulées par l'amélioration des appareillages des stations existantes et par la création de nouvelles stations.

INTERNATIONAL ASSOCIATION OF SEISMOLOGY
and
PHYSICS OF THE EARTH'S INTERIOR

RESOLUTIONS
(English text)

RESOLUTION I
(Tsunamis)

The IUGG,

Considering

that considerable damage and losses of life may be caused by tsunamis,

that the operation of the warning systems centered at the Honolulu Magnetic Observatory of the US Coast and Geodetic Survey, at the Japan Meteorological Agency and at the Meteorological Service, USSR, have been useful in reducing the risk to life in the Pacific,

that the warnings issued are based on available knowledge concerning the generation and propagation of tsunamis,

Recommends

that the present tsunami warning system be expanded through the cooperation of nations around the Pacific,

that international cooperation in interdisciplinary research concerning tsunamis be promoted by the establishment of a committee composed by members of I.A.S. and I.A.P.O.

that data concerning tsunamis be collected at the Data Centers A and B for convenient availability to research workers,

that the US Coast and Geodetic Survey undertake the compilation of a bibliography on tsunamis, that the European Seismological Commission undertake tsunami studies on the Atlantic Coast of Europe (particularly Portugal) and of Morocco and in the Mediterranean,

and Expresses

its appreciation of the interest shown by WMO in this field and assures WMO of its sincerest wish of close cooperation in this field.

RESOLUTION II

(Equipment of seismograph stations in South America)

Considering the fact that seismological studies are of primary importance in the seismic countries in South America and particularly in Bolivia, Chile, Colombia, Ecuador and Peru,

The IUGG

recommends the development of seismological research in these countries by improving the instrumentation of already existing seismological stations and by creating new stations.

APPENDIX II

RAPPORTS NATIONAUX

ANNEXE II

RAPPORTS NATIONAUX

Pages 247-257

Bolivie
Ethiopie
Irlande
Indonésie
Norvège
République Arabe Unie
Roumanie

A la fin du volume :

Allemagne
Australie
Belgique
Canada
Chili
Danemark
Espagne
Finlande
France
Grande-Bretagne
Grèce
Inde
~~Iran~~
Mexique
Nouvelle-Zélande
Pays-Bas
Pologne
Suède
Suisse
Tchécoslovaquie
Turquie
Vénézuela

Nota : Le rapport national de l'Union des Républiques socialistes soviétiques (U.R.S.S.) a été imprimé en langue russe en un fascicule spécial qui a été distribué au cours de l'Assemblée d'Helsinki.
Le rapport national du Japon, préparé par la section de Séismologie du Comité national japonais de Géodésie et Géophysique, a également été distribué au cours de l'Assemblée d'Helsinki.
Des exemplaires disponibles des rapports de l'U.R.S.S et du Japon peuvent être demandés au secrétariat général de l'Association internationale de Séismologie et de Physique de l'Intérieur de la Terre.
Le rapport national des Etats-Unis d'Amérique a été publié dans *Transactions, American Geophysical Union,* vol. 41, n° 2, June 1960, pp. 145-176.

BOLIVIE

SEISMOLOGIE

OBSERVATORIO SAN CALIXTO - LA PAZ - BOLIVIE
68°07'58"W 16°29'43"S

La Station Séismologique de l'Observatoire San Calixto de La Paz Bolivie (unique en fonctionnement pendant l'AGI) a effectué les observations courantes de séismologie avec les instruments suivants:

3 Composantes NS, EW, Z Galitzin-Wilip, 12 s. de période, enregistrement galvano-photographique.

1 Composante Z Wilson-Lamison. 1s. de période, enregistrement galvano-photographique.

1 Composante NS bifilaire type Mainka modifié, 14 s. de période, 2000 kg de masse.

1 Composante EW bifilaire type Mainka modifié, 12 s. de période, 3500 kg de masse.

1 Pendule vertical San Calixto 2.4 s. de période, 1500 kg de masse.

Ces 3 appareils à enregistrement mécanique sur papier enfumé.

Une panne à la composante Galitzin-Wilip EW a interrompu a plusieurs reprises les observations avec cet instrument.

La forme des bulletins et de l'agitation microséismique est celle indiquée dans le « Manuel d'Instructions ». Les temps sont toujours rapportés au G.M.T.

L'Agitation Microséismique a été mesurée régulièrement 4 fois par jour aux heures rondes 00 06 12 18 sur les séismogrammes des trois composantes Galitzin-Wilip.

Pendant les 18 mois de l'Année Géophysique Internationale on a enregistré 1215 séismes (121 avec une amplitude de plus de 10 microns, 15 de l'ordre de 100, ou plus, microns).

La période de l'agitation microséismique s'est maintenue presque toujours entre 5.8 et 8 secondes. L'amplitude moyenne des 5337 lectures est 0.53 microns. Les mois de juillet—septembre ont les plus larges amplitudes moyennes ; le mois de décembre présente le minimum.

La composante Z a enregistré 143 jours avec une amplitude de moins de 0.1 micron, 133 jours de plus de 1 micron ; la NS 118 et 106; la EW 60 et 85 (arrêtée pendant quelque temps).

Le bulletin définitif, contenant toutes les données séismiques et microséismiques de l'AGI et une introduction-résumé, a paru au début d'octobre 1960.

R. Cabré S.I.
Vocal de Séismologie

P. M. Descotes S.I.
Directeur de l'Observatoire
San Calixto

ETHIOPIE

SEISMOLOGY

The seismological section of the University College Observatory began its operation on a regular basis, in March 1959. It is situated on the campus of the University College, in Addis Ababa, at an altitude of 2442.5 meters above sea level, about 100 km North of the Ethiopian Rift Valley.

The Geographical coordinates are :	N 09° 01' 45" E 38° 45' 56"
The Geological formation :	Olivine basalts of the Tertiary Trap Series.

Instruments :

The original set of seismometers comprised :

One Vertical Willmore of $T_0 = 1$ second and $T_g = 2$ seconds. Two Horizontal Wood-Anderson of $T_0 = 0.8$ sec. and magnification $= 2800$.

One photographic recorder with time-base of 30 mm/minute.

Because of a periodic tilting of the piers, the Wood-Anderson were soon replaced by

Two Horizontal Willmore of $T_0 = 1$ second and $T_g = 20$ seconds.

One photographic recorder for Z, with a time-base of 60 mm/minute is expected to be in operation by January 1961.

The time marks are given by the Observatory master clock, a Riefler pendulum, Type A3, compensated for temperature and pressure variations. By the beginning of 1961, an electronic Primary Frequency Standard (accuracy 1×10^{-7}) will furnish the time marks and drive all the synchronous motors of the recorders.

Publications :

Seismological reports on the earthquakes recorded appear regularly in the Bulletin of the Geophysical Observatory, University College, Addis Ababa.

Pierre GOUIN, Director.

INDONESIA

NATIONAL REPORT OF WORK ON SEISMOLOGY (1957—1960)

Seismograph stations :

Djakarta : Lat 6°11'S, Long 106°50'E, h= 8 m.
Foundation : Riverquaternary.
Seismograph : Wiechert Z = 1300 kg.
Wiechert N & E = 1000 kg.

Bandung : Lat 6°54'S, Long 107°37'E, h = 726 m.
Foundation : Quaternary volcanics.
Seismograph : Askania.

Lembang : Lat 6°50'S, Long 107°37'E, h = 1195 m.
Foundation : Quaternary volcanics.
Seismograph : Sprengnether.
Z : T = 1,4 sec.
N : T = 3,4 sec.
E : T = 17,7 sec.

Medan : Lat 3°33'N, Long 98°41'E, h = 32 m.
Foundation : Young marine sediments.
Seismograph : Sprengnether.
Z - N - E: T = 1,5 sec.

Macroseismic work

The macroseismic bulletin — for the years 1957-1958 — is now in print ; the number of reported shocks by means of blanks has reached the average of the years before the war, all reports being based on the Modified Mercalli Intensity-Scale. Important damage to buildings was caused by the earthquake of Oct. 20, 1958 in Malang region.

Microseismic observations.

Preliminary readings are executed at every station and the results as a seismo message are cabled to the Institute in Djakarta. These data and later with the help of the seismic data from foreign-countries are used to determine a preliminary epicenter.

Preliminary seismological bulletins of all stations are prepared until December 1959.

Microseismics are read from the Djakarta seismograms only and the results are published monthly as an annex of the seismic bulletin.

Bibliography.

A. R. RITSEMA.

— *Stress distributions in the case of 150 earthquakes,* Geol & Mynb, Nw secr, 19 - Jrg, 36-40 (1957).

— *Pacific and Mediterranean earthquake mechanisms,* Trans. Am. Geoph. Un. 38 N°. 3 (1957).

— *Earthquake generating stress systems in SE Asia.* Bull. Seism. Soc. Am. 47 N° 3 (1957).

— *(i, Δ) -curves for bodily seismic waves of any focal depth.* Verh. N° 54, Meteor. & Geophysical Inst. Djakarta (1958).

— *On the use of transverse waves in earthquake mechanism studies.* Verh. N° 52, Meteor & Geophysical Inst. Djakarta (1957).

Meteorological & Geophysical Institute
Seismological Section.

Djakarta, May 27, 1960.

IRELAND

REPORT OF WORK ON SEISMOLOGY AND PHYSICS OF THE INTERIOR OF THE EARTH 1957—1959

At the Seismological Observatory, Rathfarnham Castle, the O'Leary seismograph and the short period vertical recorded continuously during the period 1957—1959. Time signals are now registered automatically and the clock correction is known to the tenth of a second. A quarterly bulletin is issued, in which it is attempted to give with accuracy the first recorded wave of each earthquake and a fuller analysis of the larger earthquakes. Records may be borrowed, for further investigations. Fast recorders are used occasionally for recording explosions etc. Some theoretical investigations have been made on fault planes and related subjects.

NORVEGE

REPORT ON THE ACTIVITY IN SEISMOLOGY AND THE PHYSICS OF THE EARTH'S INTERIOR (1957—1960)

1. *Seismological stations :*

Station name	Coordinates and elevation	Data of operation	Instruments and components		T_o	T_g	V	Paper speed mm/mn
Bergen ...	60°23'18"N 5°18'18"E 20 m	Since 1904	Wiechert	NS	10		200	15
			»	EW	10		200	15
			»	Z	4		400	15
			Electro-magnetic	NS	1	0.7		60
Isfjord ...	78°03'33"N 13°38'25"E 5 m	Aug. 1, 1958	Willmore	Z	1	0.25	max. 60.000	60
Tromsö ...	Approx. 69°40'N 19°E	Sept. 1960	Benioff	NS	1	0.25		15
			»	EW	1	0.25		15
			»	Z	1	0.25		15
Jan Mayen		1961	Electro-magnetic	Z				

2. *Macroseismic work.*

During the years 1957-1960 the following number of earthquakes were felt in Norway : 1957 - 8, 1958 - 12, 1959 - 5, 1960 - 3 until June 30.

All earthquakes are being investigated by means of questionnaires. During the three year period a paper on the earthquakes in Norway 1948-1952 has been published (Publication No. 3).

The relation of Norwegian earthquakes to the tectonics of the country and to the post-glacial uplift of Scandinavia has been studied by Kvale. A paper was presented at the Alicante meeting of the European Seismological Commission 1959. (Publication No. 4).

3. *Seismological research work.*

The increase in number of stations and the new seismographs have greatly increased the possibilities of studying Norwegian earthquakes. M. A. Sellevoll has been working on methods for determining the time of origin and the location of epicentre and has obtained better agreements with macroseismic data than by using previous methods. Travel time for Norwegian earthquakes show deviations from standard time tables. The velocities of the various phases below Scandinavia are being studied and new time tables for Norwegian stations are being prepared.

At Isfjord, Spitzbergen, more than 100 near earthquakes are registered pro year. Most of them probably originate in the fault zone outside the western coast of Spitzbergen. These earthquakes and their relation to the structural features are being studied by M. A. Sellevoll.

The study of microseisms has continued. A special study during the IGY was made by means of a Menzel-Strobach seismograph. A paper by T. Nesse is ready for publication.

During the winter of 1960-61 the sea waves will be registered at two stations on the west coast of Norway in order to study the relations of microseisms to the surf at the Norwegian coast. Instruments for this study are put at our disposal by Lamont Geological Observatory and Landeserdbebendienst Stuttgart.

List of publications.

1. - NESSE, Trygve, 1957 : An investigation of microseisms in Bergen. *Universitetet i Bergen, Årbok 1957.* Nat. v. rekke nr.11.

2. - SELLEVOLL, Markvard A., 1957 : Earthquakes in the Norwegian Channel on the 7th and the 10th of July 1954. *Universitetet i Bergen, Årbok 1957,* Nat. v. rekke nr. 2.

3. - KVALE, Anders, 1959 : Jordskjelv i Norge 1948-52. *Universitetet i Bergen, Årbok 1959,* Nat. v. rekke nr. 6.

4. - KVALE, Anders, 1960 : Norwegian earthquakes in relation to tectonic. *Acta Universitatis Bergensis.* Mat.-Natv. Serie 1960 N° 9. (in press).

Seismological bulletins :

5. - KVALE, Anders, and Sellevoll, M.A. 1958 : *Seismological Bulletin 1951-1953. Universitetet i Bergen, 1958.*

6. - KVALE, Anders and Sellevoll, M.A. 1959 : *Seismological Bulletin Isfjord. Aug. 1-Nov. 15, 1958. Universitetet i Bergen, 1959.*

7. - SELLEVOLL, M.A. and Storetvedt, K., 1959 : *Seismological Bulletin Isfjord. Nov. 17, 1958-July 1, 1959. Universitetet i Bergen, 1959.*

8. - NESSE, Trygve, 1960 : *Microseismic Readings during IGY. Universitetet i Bergen, 1960.*

REPUBLIQUE ARABE UNIE

SEISMOLOGY

1. *General :* During the period 1957-1959, seismological work at Helwan Observatory has been continued normally with the same instruments as described in the previous report. Registration was interrupted for some months due to shortage of photographic paper, and still we hope that we shall be in a position to resume publishing our monthly Bulletin as in the past.

2. *Macroseismic Work :* The following earthquakes were felt in U.A.R. during this period :

1957, April 24th. in the region of Rhodes (36°3N, 29°1E). The shock was strongly felt in the whole of the Southern Region down to Assiut (27°11'N, 31°13'E). The maximum felt intensity is 6, on the modified Mercalli scale.

1957, October 14th. in the Mokattam area, east of Cairo. Strongly felt in Cairo down to Beni Suef (29°4N, 31°6E) ; reaching intensity 6-7 in Cairo. The radius of felt area was about 100 km.

1958, June 30th. in the region of the Dodecanese Islands (36°5N, 27°4E). The shock was felt in Cairo and the southern areas, reaching felt intensity 4-5.

3. *Local Earthquakes :* Seventeen local earthquakes have been recorded with epicentral distances from 40 to 290 km. Only one of these (14. 10. 1957) was felt.

4. *Publications :* « Catalogue of near earthquakes recorded at Helwan during 1922-1950 », by Assist Prof. Azzouz Ismail.

Submitted by
The National Committee of Geodesy & Geophysics
of the United Arab Republic

ROUMANIE

SEISMOLOGIE

Le service séismologique de l'Observatoire de Bucarest comprenant les stations de Bucarest, Campulung, Focsani, Bacau et Iasi en suivant le programme de l'A.G.I. a publié mensuellement le bulletin séismique provisoire, le bulletin séismique définitif (1956, 1957, 1958), le bulletin d'agitation microséismique qui ont été expédiés aux Centres Mondiaux A, B, C, et à un nombre de 180 Observatoires et stations séismologiques. La station séismique associée de Timisoara a publié et diffusé aussi ses bulletins.

Des études concernant la structure de la croûte terrestre, le mécanisme des séismes, les magnitudes et l'énergie séismique, la séismicité et le rayonnement séismique, l'agitation microséismique, les ondes élastiques ont paru dans les publications de l'Académie R.P.R.

Le Comité National a organisé à Bucarest, en octobre 1959, une Conférence de séismologie, séismotectonique et de séismologie appliquée aux constructions concernant la région des Carpathes et des Balkans. Ont participé à cette réunion des délégués des Académies des Sciences de l'U.R.S.S., Bulgarie, Hongrie, Pologne, Tchécoslovaquie et Roumanie. Un volume contenant les communications présentées à cette conférence est en préparation.

Le président du Comité :
Prof. G. DEMETRESCU.

Les notes suivantes ont été publiées en langue roumaine :

1958

1. - DEMETRESCU G., Sur la détermination des épaisseurs des couches de l'écorce terrestre. Etudes et Recherches d'Astronomie et de Séismologie, N° 1, 1958.

2. - ENESCU D., Etude du mécanisme et de l'énergie du tremblement de terre du 18 avril 1956. Etudes et Recherches d'Astronomie et de Séismologie, N° 1, 1958.

3. - ENESCU D. et RADU C., Structure de l'écorce terrestre dans la région de Bucarest. Etudes et Recherches d'Astronomie et de Séismologie, N° 1, 1958.

4. - ENESCU D., Détermination de la magnitude des séismes à l'aide des ondes intérieures, à la station séismographique de Bucarest. Etudes et Recherches d'Astronomie et de Séismologie, N° 2, 1958.

5. - ENESCU D., Détermination, pour les ondes superficielles, de la magnitude des tremblements de terre enregistrés à la station séismographique de Bucarest. Etudes et Recherches d'Astronomie et de Séismologie, N° 1, 1958.

6. - ENESCU D., La détermination de la formule de la magnitude des tremblements de terre pour la station séismographique Iasi. Comptes Rendus de l'Académie de la R.P.R. Tom. VIII, N° 11, 1958.

7. - IONESCU Andrei Pana, Le fonds local et le fonds régional de l'anomalie de champ de gravité dans la région NE de Bucarest. Etudes et Recherches d'Astronomie et de Séismologie, N° 2, 1958.

8. - IOSIF T., Considération sur les tremblements de terre de la région de Vrancea. Etudes et Recherches d'Astronomie et de Séismologie, N° 1, 1958.

9. - IOSIF T., La structure de l'écorce terrestre sous le territoire de la République Populaire Roumaine. Etudes et Recherches d'Astronomie et de Séismologie, N° 2, 1958.

10. - IOSIF T., Détermination de la couche sédimentaire dans les stations séismiques roumaines. Etudes et Recherches d'Astronomie et de Séismologie, N° 2, 1958.

11. - POPESCU Ioan Gh., De la périodicité en ce qui concerne la fréquence des séismes en Roumanie. Etudes et Recherches d'Astronomie et de Séismologie, N° 2, 1958.

12. - RADU C., Données sur l'écorce terrestre dans la République Populaire Roumaine. Etudes et Recherches d'Astronomie et de Séismologie, N° 2, 1958.

13. - SERIAN, De l'agitation microséismique à Bucarest. Etudes et Recherches d'Astronomie et de Séismologie, N° 2, 1958.

1959

14. - ENESCU D., Contribution au problème du mécanisme et de l'énergie des sources séismiques combinées. Etudes et Recherches d'Astronomie et de Séismologie, IV^e année, N° 1, 1959.

15. - ENESCU D., Considération sur quelques ondes séismiques observées dans les stations séismographiques roumaines. Etudes et Recherches d'Astronomie et de Séismologie, IV^e année, N° 1, 1959.

16. - ENESCU D., Contribution au problème de la distribution angulaire de la densité de l'énergie dans les ondes séismiques. Comptes Rendus de l'Académie de la R.P.R., Tome IX, N° 4, 1959.

17. - FLORINESCU A., Régions présentant des foyers de séismes dans la République Populaire Roumaine. Etudes et Recherches d'Astronomie et de Séismologie. IV^e année, N° 1, 1959.

18. - IOSIF T. et RADU C., Détermination des magnitudes des séismes voisins dans les stations séismiques de l'Observatoire de Bucarest. Etudes et Recherches d'Astronomie et de Séismologie. IV^e année, N° 1, 1959.

19. - IOSIF T. et RADU C., Déterminations des magnitudes des ondes P et S à la station de Bucarest. Etudes et Recherches d'Astronomie et de Séismologie. IV^e année, N° 1, 1959.

20. - IOSIF T. et RADU C., De la détermination des magnitudes des séismes profonds de Vrancea. Etudes et Recherches d'Astronomie et de Séismologie. IV^e année, N° 1, 1959.

21. - IOSIF T., Sur les caractéristiques dynamiques des séismes dans la région Riknicul Sarat-Tecuci. Etudes et Recherches d'Astronomie et de Séismologie. IV[e] année, N° 1, 1959.

22. - SERIAN A., Projection stéréographiques des stations séismiques européennes en prenant pour centre l'épicentre de Vrancea. Etudes et Recherches d'Astronomie et de Séismologie. IV[e] année, N° 2, 1959.

A la conférence de Séismologie tenue à Bucarest, du 6 au 12 octobre 1959 ont été présentées quelques communications, qui paraîtront dans un volume spécial, à savoir :

23. - PETRESCU G. et RADU C., La séismicité et le rayonnement séismique du territoire de la R.P.R.

24. - IOSIF T. et RADU C., Les caractéristiques des déformations élastiques du foyer profond de Vrancea.

25. - IOSIF T. et RADU C., Les paramètres dynamiques de quelques séismes profonds de Vrancea.

26. - PETRESCU G. et PANA IONESCU Andrei, Propositions pour la modification du Standard d'état, STAS N° 2923/52 intitulé : Zones des intensités macroséismiques.

27. - PETRESCU G., RADU C. et PANA IONESCU Andrei, L'activité séismique dans le territoire de la R.P.R. au cours de l'année 1959.

28. - CUREA I., Séismes récents en Banat.

1960

29. - CUREA I., Un type spécial des ondes séismiques superficielles. Etudes et Recherches d'Astronomie et de Séismologie, N° 1, 1960.

30. - DEMETRESCU G. et ENESCU D., Contributions à la connaissance de la structure de l'écorce terrestre dans la République Populaire Roumaine. Etudes et Recherches d'Astronomie et de Séismologie. N° 1, 1960.

31. - DEMETRESCU G. et ENESCU D., Les épaisseurs des couches de la croûte terrestres déduites de l'étude du tremblement de terre du 19. VII. 1959. Comptes Rendus de l'Académie de la R.P.R.

32. - ENESCU D., Sur la nature des ondes séismiques secondaires observées sur les enregistrements des tremblements de terre de Vrancea. Comptes Rendus de l'Académie de la R.P.R. Tome X, N° 5, 1960.

33. - ENESCU D., Considérations théoriques sur les ondes séismiques secondaire provoquées par l'onde primaire SV. Comptes Rendus de l'Académie de la R.P.R. Tome X, N° 5, 1960.

34. - ENESCU D., Formules pour la détermination de la magnitude des tremblements de terre à l'aide des ondes séismiques Demetrescu. Etudes et Recherches d'Astronomie et de Séismologie, N° 1, 1960.

35. - ENESCU D., La distribution des signes des déplacements dans les ondes séismiques Demetrescu. Etudes et Recherches d'Astronomie et de Séismologie, N° 2, 1960.

36. - IOSIF T., Foyer séismique profond dans la Plaine Roumaine. Etudes et Recherches d'Astronomie et de Séismologie, N° 1, 1960.

37. - RADU C., Sur les tremblements de terre faibles enregistrés à la station Iasi. Etudes et Recherches d'Astronomie et de Séismologie, N° 1, 1960.

38. - RADU C., Sur les ondes séismiques Curea. Etudes et Recherches d'Astronomie et de Séismologie, N° 1, 1960.

Les bulletins

1. - Iosif T., Radu C. et Pana Ionescu Andrei, Bulletin séismique provisoire, 1957.
2. - Petrescu G., Iosif T. et Radu C., Bulletin séismique provisoire, 1958.
3. - Petrescu G., Radu C. et Pana Ionescu Andrei, Bulletin séismique provisoire, 1959.
4. - Serian A., Bulletin d'agitation microséismique 1957, 1958, 1959.
5. - Demetrescu G., Pana Ionescu Andrei et Enescu D., Bulletin séismique des stations séismiques roumaines, 1956. Etudes et Recherches d'Astronomie et de Séismologie, N° 1, 1958.
6. - Demetrescu G., Enescu D. et Pana Ionescu Andrei, Bulletin séismique des stations séismiques roumaines, 1957. Etudes et Recherches d'Astronomie et de Séismologie, N° 1, 1959.
7. - Demetrescu G., Iosif T. et Enescu D., Bulletin séismique des stations séismiques roumaines, 1958. Etudes et Recherches d'Astronomie et de Séismologie, N° 1. 1960.

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APPENDIX II

Rapports nationaux des pays membres

IMPRIMERIE MUH - LE ROUX

Dépôt légal : 4e trimestre 1961 Numéro d'ordre de l'imprimeur : 14.436