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## OVERSEAS VISITS TO FRANCE, USSR, SWEDEN, AND U.K., AUGUST - SEPTEMBER 1975

by

J.C. Dooley

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SUMMARY

The main objectives of the visit were attendance at the General Assembly of IUGG and related meetings in France, discussion of possible cooperation in geophysics with USSR under the Science Agreement, and in monitoring of nuclear explosions with Sweden. The opportunity was taken to visit a manufacturer of recording equipment for deep seismic sounding, seismological institutions at Edinburgh, and Oxford University where a BMR officer (Mr J.P. Cull) was finishing a Ph.D. course on heat flow measurement.

The first meeting attended was an informal workshop of the Commission for Controlled Source Seismology in Paris. The latest developments in studies of the structure of the crust and upper mantle in both land and marine areas were discussed. Three-component tape recording seismographs with automatic playback are standard equipment, and close-spaced recording enables detailed analysis of the structure. Vibroseis has been tried experimentally in USA and Canada.

I attended meetings on Seismology, Geomagnetism and Geodynamics at IUGG. Plate tectonics theory is generally accepted; the cause of the plate motions is believed to be some form of convection. Alternatives to the original theory that convection takes place at depths less than about 200 km include mantle 'plumes' from great depths, and whole mantle convection. The problem is not yet resolved.

Many mathematical and computer methods for treatment and display of data were presented. Working Group discussions on geomagnetism have impact on BMR procedures in data presentation. The International Geomagnetic Reference Field developed in 1975 has proved unsuitable for the Australian area; a revision of this was proposed, but will not improve it for our purposes for some years hence.

Australia's offer to hold the next IUGG Assembly in 1979 was accepted.

I also attended a meeting of SCAR Solid Earth Geophysics Working Group at Grenoble.

Potential areas of cooperation with USSR include firm proposals for absolute gravity measurements and earth tide tilt measurements in Australia; and tentative proposals for exchange participation in deep seismic sounding field parties in Australia and Siberia, and mathematical analysis of PNG seismological data for earth structure by a technique developed at Novosibirsk.

Suggestions for cooperative geological and geophysical surveys in Enderby Land were put to the Arctic and Antarctic Research Institute; however, they have completed their earth science survey in that area. Logistic advice and use of facilities at Molodezhnaya were offered for the Australian 1976/77 summer party.

The Swedish Defence Research Institute carries out concentrated research on discrimination between earthquakes and explosions, and would welcome Australian participation. Proposed informal co-operation includes exchange of data and research reports, and exchange visits as opportunity offers.

# INTRODUCTION

The objectives of this visit were:

(a) to attend the General Assembly of the International Union of Geodesy and Geophysics (IUGG) at Grenoble, France, and the related meeting of the Commission for Controlled Source Seismology at Paris;

(b) to investigate the feasibility of certain co-operative projects proposed under the USSR-Australian Science Agreement;

(c) to discuss the possibility of co-operation with Sweden in the monitoring of nuclear explosions;

(d) to study the performance of portable seismic recording equipment, whose purchase is being considered for deep crustal and earthquake investigations.

The main points of interest arising from attendance at meetings and visits to scientific institutions are summarized below. Further technical details acquired during the visits to USSR and Sweden are given in Appendices 1 and 2 respectively.

## Commission for Controlled Source Seismology, Paris 18-23 Aug 1975.

This Commission was formed by the International Association of Seismology and Physics of the Earth's Interior, to co-ordinate exchange of ideas and data relating to the structure of the Earth's crust and upper mantle, the main emphasis being on seismic waves generated by explosions or other artificial sources of vibrations as distinct from earthquakes.

The Paris meeting was in the form of a workshop 'Comparative interpretation of seismic explosion data'. About 40 people attended, including Prof. A.L. Hales (ANU) and myself from Australia. The organization was informal - there was no prepared list of speakers. The program was divided into six sessions on various aspects of the structure of the crust and upper mantle in continental, oceanic, and transitional areas, and in relation to plate boundaries. I spoke on our recent crustal survey in eastern Papua, and on the interpretation of deep crustal seismic reflections in Australia.

Results were presented of many investigations conducted on a co-operative basis by Western European countries; a fairly standard model for the main features of the crust in that area is emerging, with many local variations in detail. Tape recording with triple-component seismographs, and subsequent analysis on digital computers, are standard procedures.

Techniques using the 'Vibroseis' system of artificial vibrations, developed commercially for use in oil exploration, have been used in deep crustal studies in USA and Canada with some success.

Marine surveys show increasing crustal thickness away from mid-ocean ridges, in conformity with the predictions of plate tectonics. Long strings of sonobuoys and ocean-bottom seismometers are commonly used to improve the quality of the data.

Abstracts or summaries of papers presented will be collated and distributed, but the full proceedings will not be published.

<u>XVI General Assembly of the International Union of Geodesy and Geophysics, Grenoble, France, 25 Aug - 6 Sept 1975</u>.

The International Union of Geodesy and Geophysics (I.U.G.G.) is the coordinating body for geophysical investigations which require cooperative efforts from various nations. 71 countries are members of IUGG.

The I.U.G.G. comprises seven associations, namely:

I.A.G. - International Association of Geodesy

I.A.S.P.E.I. - International Association of Seismology and Physics of the Earth's Interior

I.A.M.A.P. - International Association of Meteorology and Atmospheric Physics

I.A.G.A. - International Association of Geomagnetism and Aeronomy

I.A.P.S.O. - International Association of Physical Sciences of the Ocean

I.A.V.C.E.I. - International Association of Volcanology and Chemistry of the Earth's Interior

I.A.S.H. - International Association of Scientific Hydrology

General Assemblies are normally held at intervals of about 4 years. During these, business meetings of the above Associations and their Working Groups, Sections, and associated Committees are held. Symposia on scientific subjects, generally of interest to two or more associations, are also held; throughout the period of the assembly there are several such symposia running continuously.

BMR has activities closely related to some aspects of the spheres of interest of all of the Associations except I.A.M.A.P.

It was impossible for me as the only official delegate to attend all relevant sessions. Mr B.C. Barlow, who attended the Assembly at his own expense- attended the IAG sessions, and I distributed my attendance between IASPEI, IAGA, and the International Geodynamics Project. I presented a paper in the Symposium on 'Analysis, processing and interpretation of geophysical data'.

Many advances were reported relating to plate tectonic theory, which is almost universally accepted now, although the causative mechanism of the plate motions is not understood. It is generally believed to be some form of convective motion in the mantle; originally this was supposed to be confined to the top 200 km or so of the mantle. More recently localized 'plumes', upwelling from the lower mantle and spreading out under the solid lithosphere, were proposed; however, several speakers at Grenoble claimed that this theory is untenable. Many previous objections to convection involving the whole mantle have been shown to be invalid, and this now appears to be a plausible mechanism.

Other papers discussed the causes and effects of stresses at the edges of plates and within plates, studies of oceanic trenches where crustal material is supposed to descend into the mantle, composition and physical state of the mantle and crust, the results of the U.S. (JOIDES) deep sea drilling program, and the relevance of heat flow to geodynamics.

Many computer applications were reported for storage, retrieval, analysis, and display of geophysical data. Analysis techniques included spectral analysis, separation of signals from noise, identification of long-term trends, and pattern recognition by computers where data from diverse disciplines are involved.

Of special interest to Australia was discussion of the International Geomagnetic Reference Field (IGRF), defined in 1965 with provision for updating, using the then predicted secular variation. The predictions turned out to be seriously in error for the Australian area, which makes IGRF unusable for applying corrections to marine and airborne magnetic surveys. This problem was appreciated by overseas workers, but the proposed revision of IGRF will do little to alleviate the position in our area for some years; thus it is necessary for us to define an Australian Geomagnetic Reference Field.

Several approaches to improving accuracy of geomagnetic field measurements, and facilities for automatic and unattended recording, were reported. Other IAGA Working Groups were attended dealing with standardization of observatory procedures and international data exchange.

Australia made an offer to hold the next IUGG General Assembly in 1979; being the only offer, this was accepted.

Scientific Committee for Antarctic Research (SCAR).

I attended a meeting of the Solid Earth Geophysics Working Group of SCAR, which was held during IUGG at Grenoble for convenience. Topics discussed included preparation of gravity and magnetic maps of Antarctica, possible use of satellites for surveying and data transmission, recommendations for further seismographs and heat flow measurements, an international cooperative geophysical project in the Scotia Arc region, and a joint symposium with the Geology Working Group to be held at Madison, Wisconsin, USA in August 1977.

United Kingdom

The main purpose of the visit was to inspect and discuss the performance of field seismological tape-recording equipment manufactured by Racal Thermionics Ltd of Southhampton. My visit conveniently coincided with the firm's annual exhibition at the Royal Lancaster Hotel, London, where the equipment was on display. It was mainly developed for local earthquake recording, but has also been used successfully for recording explosions in deep crustal sounding. At Edinburgh, I was shown results of recordings by the Global Seismology Unit of the Institute of Geological Sciences, who have operated 9 Racal seismic stations in an array in Scotland for several years with satisfactory performance.

I also visited the International Seismological Centre in Edinburgh, which collates and summarizes data from many countries including Australia, and Dr Bamford of Edinburgh University, who is initiating a program of deep crustal investigations; all these were conveniently located at one one site.

At Oxford University, I visited Mr J.P. Cull of BMR, who had been carrying out research into heat-flow measurements under a Public Service Board Scholarship. He has since completed his Ph.D. course and returned to BMR in December 1975.

USSR-Australia Science Agreement

I visited various institutions in USSR in order to find out more about several proposals which were included in the lists discussed and agreed to by the Australian delegation visiting USSR in December 74, and the reciprocal visit to Australia by a Russian delegation in June 1975. The items which appeared to be related to the work of my Section are listed below with appropriate comments.

Tectonics of the SW Pacific and comparative areas in USSR. A comprehensive study of this topic should incorporate seismic, gravity, and magnetic data, and BMR has acquired much in these disciplines over many years. My objective was to find how geophysics could contribute. However, it was clear that the geophysicists at Moscow and Novosibirsk had no interest in, nor even knowledge of, the proposal, which was intended mainly as a palaeontological and stratigraphic study, and outside my sphere of interest.

Tidal gravity. USSR proposed to send a few recording gravity meters to record tides of the solid earth in Australia, and one or two tiltmeters for recording tidal tilting.

The gravity meter proposal has been forestalled by a Belgian co-operative project currently in progress; the results of the latter may indicate that further measurements are desirable, but we would not consider a USSR project till 1977 or probably later. Nevertheless I had the opportunity to see and discuss their equipment (manufactured by Askania of Germany), recordings, methods of analysis, and results in some detail.

The tidal tiltmeters were also examined and discussed in detail, and appear to have some advantages over the Belgian equipment which we are currently operating at Armidale, N.S.W. As we have had difficulties in getting satisfactory results at Armidale, comparison of the performance of a Russian tiltmeter would be valuable. A deep mine shaft or tunnel (50 m or more) is required; so far we have been unable to locate an accessible site other than Armidale not currently being worked. However we are actively considering accepting the loan for 1977.

Precision gravimetry. USSR has recently developed a set of equipment for precise absolute gravity measurements, which was still undergoing performance tests. Subject to these being satisfactory, the Russians proposed that the equipment should be sent to Australia/SE Asia in 1976, 1977, and 1978 to attempt to measure secular variation in gravity.

(A large gravity gradient in this region suggests that secular variation may be more readily detectable here.) The Russian proposal envisages measurements at several sites in Indonesia, but political relations may preclude this. We recommend accepting the offer for measurements at Australian sites in late 1976.

I was unable to inspect the equipment as it was in transit between Novosibirsk and Moscow. Preliminary tests at Novosibirsk and Irkutsk indicate satisfactory performance.

Deformation of the Earth's crust. In relation to mechanism of tectonic deformation and physics of earthquakes, the objective was to exchange ideas and information. The low frequency of earthquakes in Australia does not favour intensive studies; our main interests have been in relation to PNG.

I saw some simple but very precise bubble tiltmeters for measuring long-term tilts at IPE, capable of measuring tilts of a few seconds of arc per year. They have been used successfully in the Kamchatka Peninsula and near Moscow.

Another sub-title under this heading was 'Studies of the Earth's crust by seismic methods'. IPE now work in this field almost entirely at sea or at continental margins. IGG, however, do much work in Siberia, concentrating recently in the vicinity of Lake Baikal. They have developed some individual techniques which have also been used in Antarctica, and having translated several of their papers I was interested to get further and more recent information. I believe it would be useful to send a BMR geophysicist to work with one of their field parties, but it would be essential that he could speak Russian. No one suitable is available at present.

Interpretation of geophysical data. At IPE, Prof Strakhov described his group's work on interpretation of gravity and magnetic data. This was very interesting and potentially valuable for application in BMR, but there was no obvious case for a joint project.

At NCC, many sophisticated computer techniques have been developed for deriving crust and mantle structure from earthquake wave travel times. A useful project could be proposed for one of our geophysicists to visit Novosibirsk to analyse the PNG data by their techniques, which have taken several years to develop and perfect. However, language problems would again present a difficulty.

<u>Geomagnetic study of mantle conductivity</u>. The proposal in December 74 was to establish several geomagnetic observatories at various latitudes along a geomagnetic meridian passing through Australia and Siberia and record for several years, in order to study the electrical conductivity of the deep mantle of the Earth. This item was omitted from the list prepared by the Russians for their June 75 visit, but subsequent cabled advice confirmed that the project was still intended to be included.

As our long-term program calls for a better distribution in latitude of magnetic observatories, it seems that this could be a fruitful project for co-operation. However, I was unable to find anyone in USSR who knew of the project, or who knew who initiated it (this may have been because many people were absent on holidays).

<u>Geological and geophysical studies in Antarctica</u>. This project was proposed by the Australian scientists in the December 1974 visit; it was not on the list compiled by the Russians for their return visit, as this included only those projects which were the concern of the USSR Academy of Sciences. There would of course be scope for co-operation under SCAR if not under the Science Agreement.

It was known that USSR had done geological, gravity, and aeromagnetic surveys in the Lambert Glacier/Prince Charles Mountains area, a deep crustal seismic sounding profile across the Lambert Glacier valley, and also geological work in Enderby Land. Our geological parties have recently completed work in the Prince Charles Mountains region and are commencing a program, expected to last for several summer seasons, in Enderby Land. Thus there appeared to be scope for joint interpretation of results; and possibly joint field operations in Enderby Land.

I saw the final interpretation of the deep seismic profile at IGG, in the form of a hand-coloured section on a dye-line; this was said to be the only copy available, and plans are in hand to publish it. At AARI, I saw hand-coloured geological maps of Prince Charles Mountains and Enderby Land, and gravity and magnetic maps of Prince Charles Mountains. Some of these results had been published already in Russian.'

It turned out that they had completed their geological field work in Enderby Land two years ago, and were now mapping in the Weddel Sea area; they had also carried out gravity and aeromagnetic surveys. There was no geophysicist available who was familiar with this work, but I understand that the data are still being analysed.

Thus there is no possibility for a joint field project in Enderby Land; however, the Russians will be happy for our relief vessel to visit Molodezhnaya, for our parties to use their airstrip, and to provide advice on weather conditions. They gave valuable advice on seasonal climatic and ice conditions in the area. (A visit to Molodezhnaya has since been made by the ANARE expedition during the 1975/76 season).

Marine gravity

During the trip to Novosibirsk, I was accompanied by Dr Mikhail Kogan of IPE. He has carried out gravity measurements on many of the USSR marine expeditions, and has interpreted and published papers on the results. He has also partaken in joint co-operative marine surveys with Lamont Geological Observatory, New York, and has spent some time there analysizing the results, including those of a survey on the Kuril-Kamchatka Arc (Kogan, 1975).

He showed me a draft of a paper on the gravity results acquired during the cruise of the Vitiaz in the S.W. Pacific during 1970-71. He said this had been accepted for publication in Journal of Geophysical Research, and that the data were available on request from WDC Moscow (these have since been obtained, in the form of maps and profiles on micro-film). The cruise included traverses across the Bismarck Sea, Coral Sea, and Tasman Sea.

Swedish Defence Research Institute

Dr Dahlman and his staff began by giving a series of prepared talks illustrated with slides and overhead projector. He explained the history of international agreements on nuclear disarmament and their involvement.

He and members of his staff explained their methods of discrimination between nuclear explosions and earthquakes, based on location, depth, MB/MS magnitude ratio, ratio of initial P amplitude to coda, and frequency of the signal. No one method works for all events, but by using all available parameters they claim a certainty of 1% in their identifications. They claim to be able to detect explosions as small as 1 to 3 kilotons in USSR, and about 10 kilotons in USA.

On the following day (23rd) Dr Dahlman accompanied me on a visit to Hagfors Observatory, about 500 km west of Stockholm near the Norwegian border. This is the main station for a network of three stations forming a triangle with sides about 30-50 km, and a local array of seismometers at each station designed for signal/noise ratio improvement. A seismic event is detected automatically, and fast recorders are triggered to enable accurate location, based on the time differences across the array for azimuth, and S-P arrival time difference for distance. Regional corrections are applied using calibration by accurately located events listed by ISS.

Preliminary locations are calculated almost immediately, and a preliminary daily bulletin listing events is compiled; the information is telexed to Stockholm where events are identified as earthquakes or explosions. Obvious false alarms are eliminated, and a final bulletin is issued two days later.

In addition, special information bulletins are published (about two per year) giving details of recordings for typical explosions and earthquakes in selected areas, or for events of particular interest such as Indian and Chinese nuclear explosions. The series may be discontinued when a comprehensive and representative set of events has been reported.

Sweden has for several years co-ordinated a program for monitoring nuclear explosions in co-operation with Canada and Japan. As Sweden is in the P wave shadow zone from Tahiti, they are interested in extending the co-operative group to the southern hemisphere, and have recently reached an agreement with New Zealand.

It was suggested by Dr Dahlman that co-operation between Australia and Sweden should be informal, at least in the first instance - i.e. agreement by exchange of letters rather than formal government documents. The following areas of co-operation were proposed:

1. Exchange of data in the form of regular bulletins, and further details of events of particular interest to be telegraphed on request.

2. Exchange of research reports and papers.

3. Research and development of techniques for detection and identification of underground nuclear explosions, as a joint project if warranted.

4. Mutual exchange of visits by scientists as opportunity offers.

(1): I felt that BMR would probably not wish to receive daily bulletins, but would be interested in periodical lists of identified nuclear explosions and special information bulletins. Data from Australian stations are freely available on request. We could send them our regular bulletins, which are issued monthly about six weeks after the end of the relevant month, and which contain data from all Australian stations (i.e. not just BMR). We also telex information several times weekly to USGS and could repeat this to Sweden if desired. The Seismological Research Observatory, currently being installed at Narrogin W.A. by USGS, will be operated by BMR, and data from this could be telexed immediately. Information from events of particular interest could be telegraphed on request as soon as available; however, data from some of the more remote stations can be several days late.

(2): We would welcome exchange of research papers, though the flow would probably be mostly from Sweden to Australia.

(3): It is difficult to see how BMR could make a significant contribution in view of present commitments and staff ceilings, although there would be scope for this in connection with explosions in the Pacific Ocean.

(4): We would of course welcome the Swedish scientists at any time. Visits by Australian scientists are likely to be limited to those which can be accommodated in overseas visits made chiefly for other objectives.

The Australian contribution to a co-operative program could of course be substantially increased if the Government decides to take an active part in monitoring nuclear explosions in connection with participation in the test ban treaty.

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# APPENDIX 1

## VISITS TO SCIENTIFIC INSTITUTIONS IN USSR

Following are details of discussions held with Russian scientists during the period 8-20 September 1975. The discussions were directed towards evaluating potential areas for co-operation under the USSR-Australian Scientific Exchange Agreement. This Appendix and Appendix 2 have been prepared from tape-recorded notes made daily during the visits; they are intended to amplify the technical details of topics mentioned briefly in the text of the report, for the benefit of interested specialists. The notes have been collated under various disciplines - Earth tides, seismology, gravity, geomagnetism, and Antarctic geology and geophysics.

## EARTH TIDES

### Tidal Tiltmeters (Institute of Physics of the Earth)

I spoke to the Director of the Institute, Professor Sadovsky, who gave me a general outline of the activities of the institute. Following this I met Professor Ostrovski who is the expert on the tidal tiltmeters. He gave me an excellent description of the principles and operation of the instrument and showed me an instrument itself, the instrument they used for calibration, and several records obtained with the instruments. He also discussed the type of investigations which they carry out with this and some of the results.

The instrument is fundamentally the same as a horizontal seismograph; it has a basic fundamental period of only five seconds and feeds a photo-electric sensing device with a galvanometer with a period of 20 seconds. There is an optical magnification system. A light beam is reflected through a multiple path from stationary mirrors and a mirror attached to the beam of the seismograph, and the light ultimately falls on a split photo-electric cell detector which feeds its output into another galvanometer in a recording chamber. The light beam is then photographically recorded on a spool recorder which holds enough paper to operate for between one week and one month unattended, depending on the speed of the paper. The light beam is also deflected by a semi-silvered mirror on to a graduated scale which can be inspected visually. The overall magnification of the system is between 5000 and 8000. The system is damped electromagnetically. The beam of the pendulum is made of an aluminium alloy and has a very small temperature coefficient, but nevertheless the instrument is always installed in a chamber with very small temperature variations.

The instrument is calibrated by means of a tilting table which consists of a marble slab, about 1½ metres long and 3/4 metre wide, which balances on two knife-edges and can be tilted along the axis of the tiltmeter beam. Attached to the tilting table is an arm which passes through a hole in the wall into another room so that the instrument may be undisturbed during calibration. The height of the arm is measured by a microscope, and by adding small weights to the arm the table is tilted through a measured angle. Currents are then applied through an elector-magnetic coil to restore the beam to a null position. By this means the ratio between the mechanical and electromagnetic calibration is determined.

When the instrument is set up, an electromagnetic pulse is applied twice daily to check the variations in calibration. The instruments are periodically recalibrated on the tilt table at Moscow. Originally they were done once every year, but it was found that the variation in the calibration was so small that now it is felt quite safe to leave the mechanical check for a period of ten years.

Calibration of an instrument takes about a day after setting on the tilting table. They prefer to do the more accurate calibration during the night when there is less disturbance from other people in the building and traffic, but they can start the process during the day and get to within about 1 percent, and do the more accurate calibration during the night. Calibration can be done to something of the order of a millisecond of arc, but the overall accuracy in determination of Love number is of the order of 1 percent. Installation apparently takes only a few hours.

It is claimed that the instrument has very small or zero drift. This can be detected in the first place by studying the behaviour of the instruments when new; they drift comparatively rapidly at first, but after a period of ten days asymptotically approach a steady drift rate, possibly zero. The difference between instrumental drift-rate and real ground movement is checked by running the instrument alternately in two directions of 180 degrees rotation, or by running two instruments simultaneously side by side with 180 degrees difference in orientation.

I am not sure whether the ten days drift applies only to a new instrument or whether this happens every time an instrument is moved; however, the ease of setting up compared with the Melchior tiltmeters makes possible such tests as interchange of instruments, rotation of the same instruments through different azimuths, tests at different sites within a mine tunnel, and similar tests which help to sort out instrumental effects, cavity effects, topographic effects, and true tidal or long-term secular variation. A very rapid acting clamping device enables the instrument to be made ready for transport in a matter of a few seconds.

The instrument is hermetically sealed and contains a desiccating agent; by this means it is claimed that it may be operated in conditions of extreme humidity without any adverse effects. The recording apparatus is also hermetically sealed and designed for operation under damp conditions.

The instruments may be used for measuring long-term tilt such as that due to stresses or strains associated with earthquakes or tectonic movements. In studying these it was noticed that on some occasions a long-wave period of some minutes appeared to precede certain large earthquakes. At this time the instruments had a period of only some tens of seconds, but following this it was decided to change the design to be able to record at very much longer periods into some hundreds or even more than a thousand seconds. The achievement of this with the fundamental five-second pendulum period and a 20-second galvanometer period was explained as due partly to the fact that the instrument is damped, and secondly that photo-electric recording is directly proportional to angles of tilt, and not to velocity as is the case with electromagnetic seismographs, which are therefore more sensitive to the higher-frequency recordings. From the instrument response curves which I saw the maximum sensitivity appears to be in the region of about 10 to 30 seconds with a slow fall-off decreasing by factor of perhaps 10 or so to periods of 100 or 1000 seconds. Large earthquakes are, of course, clearly recorded, but the amplitude ratio of the normal earthquake waves to long period waves is very much smaller than with a seismograph. The short period of the pendulum itself appears to contribute to the stability of the instrument.

On the records I inspected there are signs of noise which it appears has a period of about 60 seconds; this appeared to some extent on all records but with varying amplitudes from about a fraction of a millimetre up to 2 millimetres. Ostrovski considers that these are due to long period waves in the ocean. They are of course recorded to a much less extent on Russian instruments than on Melchior's instruments because of the damping of the Russian instruments.

Ostrovski claimed that the instruments could be operated in shafts about 10 metres deep, and on studying some of the reprints which he gave me it appears that the temperature effect, at least in the latitudes in which the Russians have used the instruments, are about three times as great in the north-south direction as they are in the east-west direction, and they get their reliable results from the east-west component. Tests have been made by operating instruments at different sites and throughout the year so that the effects of diurnal temperature variation (which is apparently much less in winter than in summer) can be estimated and corrected for. It is claimed that measurements made in hard rock, and particularly in tunnels in hard rock, show the greatest scatter; less scatter is found in soft sand rocks and clays and also in shafts rather than in tunnels.

Ostrovski claims that the factor $\gamma$ , which can be determined to about $\pm$ 1 percent under ideal conditions, is always greater when measured with Melchior pendulums than with the Russian pendulums. He has made some observations at Warmifontaine to compare the instruments. He, of course, considers the Russians instruments are best but admits that Melchior considers that the Belgian instruments are best.

The records are scaled manually by a contracting agency who returns the scalings in forms of milliseconds of arc in tabulated form. They are then harmonically analysed on an electronic computer, and plots of hourly values, or on a shorter time scale of monthly values, are made. These of course show any major errors in the scalings.

The instruments may be recentred when secular movement takes them off-scale, apparently by quite a simple operation. They may be operated either from mains power or from batteries. Batteries will last for about a week to a month's operation.

Instruments have been used for testing ground motion in the vicinity of large dams during construction and filling; in some cases motion on faults which cross the dam site have been measured; also for studies in connection with forecasting of earthquakes in seismically active areas such as central Asia, for study of long-term tectonic movements as in the vicinity of Lake Baikal and other regions, and for study of free oscillations of the earth. Ostrovski showed me reprints of several unpublished papers, one of which he was hoping to present at the Grenoble General Assembly, but was unable to attend. He has offered to post these to me.

The instrument I saw gave the impression of excellent instrumental construction, engineering, and finish, and inspired considerable confidence in the performance. The recording apparatus is in a separate chamber and may be remote from the tiltmeter itself so that the tiltmeter is not disturbed by entry of the observer during periodical checks.

On the whole I was very impressed with the claims of the performance of the instruments and the amount of study and development which appears to have gone into them, and feel that they will be well worth trying in Australia if a loan can be arranged in the future.

Tidal gravity meters (IPE)

Professor Pariisky and Professor Pertzev of the Earth Tidal Gravity Group described their network, which uses about ten or eleven Askania type gravity meters, some type 11 and some type 15. Their main station is at Talgar near Alma Ata in Central Asia, and here they have several instruments recording simultaneously. The instruments there have been running continuously for 15 years and they claim that they have very accurate value of the factor $\delta$ , which is about 1.16. The ocean corrections are very small although not completely negligible; they have been calculated but are less than the errors of accuracy of determination of the factor.

The type 11 gravity meter records photographically and shows a certain amount of drift; the type 15 records on an ink chart and shows very little drift - on some records which I saw, this was true for periods of some weeks. Calibration is achieved in the first place by running the meters up and down a calibration range and comparing this with the placing of a ball on the beam, which is typical of the Askania meters. This is repeated before and after installation and on a number of occasions and they claim there is virtually no change within about 0.1 or 0.2 per cent, which is accurate enough for tidal work. The recording instrument calibration varies substantially, and this is calibrated periodically by disconnecting the gravity meter and applying a standard current and noting the deflections obtained.

They consider that a period of four months recording at one stations is insufficient for an accurate determination of $\delta$ and consider that at least 12 months, preferable two years, is desirable. The local variations and local effects on $\delta$ such as topographic effects, temperature effects, cavity effects and so on, are much less than with tiltmeters, and they claim that with proper correction for the loading of ocean tides, the variation over most of Asia and Europe is very small; nevertheless there are virtually no results yet from the Southern Hemisphere, and it will be of interest to see whether these conform to the Northern Hemisphere. They have tested their meters in a temperature-controlled chamber in which cyclic variation of temperatures with amplitudes of $3^{o}$ or $6^{o}C$ have been applied, and with periods of six hours, nine hours, fifteen hours etc.; they find that it is necessary to keep the chamber in which the gravity meter is recording temperature stabilized within about 0.1 or $0.2^{o}C$. Tests have also been made for non-linearity of the recording apparatus. The gravity meter reading itself is said to be quite linear as shown by tests, but the recording apparatus has a non-linear response; this is measured and corrected for.

The records I saw showed a very small cyclic effect with period probably 1 or 2 minutes; Pertzev claimed that these were due to oceanic microseisms and were not associated with the temperature control cycling. In the type 11 gravity meter, temperature control was operated by the usual switching off and on of thermostats at intervals of 2 to 3 minutes, but in the Askania 15 type gravity meter a smooth variation of the temperature control currents is applied to avoid sudden changes in slope of the tidal chart.

They have detected the fortnightly tidal factor MF, as indicated in the paper by Bazinkov, with an amplitude of about 3 microgals, and also the monthly tidal variation with an amplitude of about 1 microgal, by spectral analysis of the records.

The factors $\gamma$ and $\delta$ are not very useful for resolving the differences between various earth models; they have computed the effects of many models which give different results for the Love numbers k and h, but the variations in these are such as to have opposite effects when used in calculating $\gamma$ and $\delta$ , and tend to eliminate each other. Thus there are only very small differences, particularly in $\delta$ .

They have attempted to resolve the tidal components K1 and P1, which they claim would be related to movements of the solid inner core, which may be related to occurrences of earthquakes near the surface and changes in the rate of rotation of the earth and the nutations, etc. of the pole.

The method of harmonic analysis used is that developed by Pertzev, but he claims that it makes little difference with good records over a long period which method of analysis is used, as all have been tried and give very similar results. The main difference appears to be the way of allowing for missing values in the records.

Gravity meters are installed in a double-walled building, with thermostatic control of the temperature in the outer corridor. Tests have been made for magnetic effects; although a magnetic effect does occur with large fields it is too small to be noticeable for normal diurnal variations. Also tests made for barometric effects have shown these to be negligible.

## Bubble tiltmeters

Dr Dobrokhotov has developed a very simple instrument for recording long-term tilts. It consists basically of a standard astronomical telescope bubble with sensitivity of 1 second per division; later models have a sensitivity of ½ second per division. Light is fed in through both ends of the bubble tube and illuminates the ends of the bubble; these are seen through lenses as spots which are recorded on a photographic record. The bubble is adjustable in length through allowing the air into a chamber at one end of the bubble tube.

Temperature effects are largely eliminated by the recording of both ends of the bubble, as any variations in the length of the bubble during operation will be cancelled out; nevertheless the instrument is normally used in a vault or a temperature stabilised room. It is claimed that this has zero drift, and I gather that this is a higher order of zero drift than the apparatus of Professor Ostrovski. The bubbles are, in general, non-linear and special tests have been made on them at Potsdam - corrections have to be made division by division along the length of the bubble tube, and corrections are tabulated for bubbles of different lengths. The resulting curves are highly irregular and show corrections of up to half a second.

They have only four such instruments in operation at present; two have been used on a volcano in Kamchatka, and the other two are recording near Moscow. They are used in two pairs, for north-south and east-west components. The instruments may be operated either from a power source or from batteries. The clock mechanism turns on the recording light at intervals of either 1 hour or 12 hours. If the 12-hour interval is used they may run unattended or without change of paper for periods of up to one year. This is the normal mode of operation for determining secular drift. Curves I was shown, show drifts of several seconds per year.

I saw an actual instrument operating under test in a vault in the laboratory; this is not of course a site for recording tilt. The bubble tube is about 15 cm long.

Normally three tubes are mounted side by side and spots are obtained from all three to ensure reliability of recording and elimination of stray systematic effects peculiar to one bubble; however, the curves seem to run very nearly parallel from all three bubbles.

Earth Tide Observatory

I visited the Krasnaya Prakha Observatory about 40 km SW from Moscow. I was accompanied by Prof. Pertsev, and Dr. Grinov was the officer on duty at the Observatory. They have a variety of tidal recording equipment, both gravity meters and tiltmeters operating there, but owing to proximity of buildings, habitation, and traffic, the site has become too disturbed and is now used mainly as a test station. The vault in which the instruments were installed was in a very old building and suffers considerably from humidity. They are in the process of moving their apparatus into a newly constructed vault.

Apart from Askania tidal gravity meters there was one recording tidal gravity meter constructed by Grinov. This was said to be similar to the Askania gravity meter but it had a quartz movement, which enabled considerably higher magnification of the output of the gravity meter, the movement of the beam being set to a much longer period than the Askania gravity meter; however, the sensitivity of the recorder was less and this compensated for the increase in sensitivity of the gravity meter. I am not clear what the advantage in this was; however, he has been experimenting with trying to eliminate the drift of the quartz system. At present this is 3-4 milligals a day, similar to that obtained with Worden and other quartz gravity systems, but he claims to be able to reduce this to about 1/10 milligal per day and possibly even zero. I gather he has not got a satisfactory working model constructed yet. The principle of operation is that the drift occurs because of a tendency of the main astatising spring to contract and raise the beam; he counteracts this by applying torsion to the horizontal fibre supporting the beam in such a sense that the tendency of the fibre to unwind exactly counteracts the tendency of the spring to contract. He says that this is simple to draw or explain but very difficult to achieve in practice.

He has also constructed a quartz movement tiltmeter in which he says the suspension is similar in principle to the Melchior type, but the method of recording is different and the instrument is very much smaller than our Melchior pendulums. He showed me the first model, which was in a case about 10 cm by 5 cm by 10 cm high. This is at present used only to check tilts of the pillars on which gravity meters are set up for recording. Other instruments of this sort are used in other observatories in Russia. He showed me the apparatus which they used for winding quartz springs, which he claims gives almost 100 percent success; it consists of a quartz cylinder or similar material and is driven by a motor with a screwthread which causes the cylinder to move slowly along its axis as it turns. The melted quartz fibre is allowed to spin onto this rotating cylinder and according to the speed of the motor the thickness of the fibre in the spring is varied.

Earth Tide and Seismic Observatory, Novosibirsk (IGG)

I visited the Seismic and Tidal Gravity Station operated by the Institute, which is situated about 7 km away from the University. Seismic equipment was a standard type of seismometer with vertical and horizontal components. The period of the short period seismograph is about 1 s, and of the galvanometers 0.25 s, and for the long period I believe the seismograph periods were 15 s and the galvanometers about 30 or 40 s. They claim that they have no trouble with drift of the long-period seismometers. The seismometers and the tidal apparatus are installed in separate huts, both of them with inner and outer brick walls. The tidal equipment was Askania type GS 11 gravity meter. This had just been sent to Kamchatka for a period of about 2 years for comparison with an instrument whose calibration was suspect, and had not yet been set up after return. They hope soon to replace it with a GS 15 gravity meter. The absolute gravity apparatus, which had been constructed in Novosibirsk, had just been crated and sent to Moscow. Measurements have already been made at Novosibirsk and at Irkutsk; as these are only the first measurements at each site there is no evidence yet of course of secular change in gravity. No tiltmeters were currently in operation at Novosibirsk.

## SEISMOLOGY

### Mathematical analysis of seismic data

At the Computing Centre of the Mathematical Institute of the Siberian division of the Academy of Sciences, Novosibirsk, I spoke with Prof. Romanoff and Dr Anikonov of the Geophysical Section. They have developed a mathematical approach with practical solutions to many geophysical problems.

The first of these discussed was a case of the study of distribution of seismic velocities in a segment of the Earth's outer sphere, perhaps lithosphere or a little deeper. It is assumed that there are many seismographic recordings of earthquake sources within the segment studied, so that the distribution of travel times as a function of distance and position within the segment is known and can be represented by a continuous function. The velocity, or rather the slowness, of the travel times as a function of position within the segment studied is represented by two terms: one a function of radius only, which is taken as being well known; and the other a function of horizontal position in two components and the depth within the segment, which is small compared with the first term. The problem then amounts to solving an integral equation. They showed me as an example a series of contours for the crust in the Lake Baikal region, with a relatively low velocity in the horizontal distribution in the centre of the area, and the perturbation term in the radial velocity also showed a low which had a depth of about half-way through the slab studied; this I believe would have resulted in very nearly a low-velocity layer in the complete term. The method gives non-unique answers in the case where the velocity as a function of depth is non-monotone increasing.

The next problem mentioned was a method of calculating the positions of hypocentres within a given area. This seemed to be related to the determination of the distribution of velocity as a function of depth from residual travel times of earthquakes, and it was shown that this could be done by a stepwise procedure in which the velocity is determined to quite a shallow depth in the first instance, and using the known velocity distribution to that depth it was then possible to extend, using longer travel time paths, to greater depths. Once again the problem of non-uniqueness arose if there was a velocity reversal.

Another question was the study of signals received at an array in which the signals were functions of X and Y co-ordinates as well as time, and the inversion of this into a velocity structure and the possibility of detecting changes in the shape of the refracting-reflecting surfaces.

Another problem was the identification of earthquakes which serve as generators of tsunamis, and distinguishing these from those which do not. The conclusion appears to be that there is a favourable depth zone for tsunami generation between about 30 and 40 km, and that earthquakes with an inclined fault plane solution were more favourable than those with horizontal or vertical fault planes.

The mathematical problem of solution of differential equations in which the derivatives of first or second order with respect to both time and a vector of n dimensions are related, and the generalized problem of inverting this equation to obtain solutions, have been considered. Many geophysical problems form special instances of this very general type of equation. It is not known yet whether trying to get a general solution for the equation will have any practical value over solving the simpler equations for special cases, in which most of the terms in the general equation would be zero.

A very detailed analysis has been made of the earthquakes in the Kamchatka region, in which the earthquakes are assumed to lie within a bounded zone and to be of such a density that they can be represented as a continuous distribution within that zone, so that the times of travel to stations at a network of 16 seismograph stations within the vicinity of the zone can be represented as a continuous function of the position of the earthquakes. It is assumed that the hypocentres of these earthquakes have been accurately determined. Altogether 1000 earthquakes were used to determine the distribution within the zone, which corresponds to a presumed dipping subduction slab. A solution shown gives velocity as a function of depth and also position at several (four, I believe) cross-sections across the slab, and also a general function of the velocity versus depth averaged over the slab or showing the zones in which the velocities occur at given depths. Also a section has been taken along the slab itself and shows a pattern of velocity distributions within the slab or at the upper surface of it. I asked whether this might be applicable to the New Britain trench region and indicated approximately the distribution of seismograph stations around that area, and they consider that this might lead to a feasible solution. The program and refinements of the program, putting the data into the right form and so on, took a total of about 5 years work, but now that the method is established it can be applied using, in the case of the Kamchatka Peninsula problem, about 6 hours of their computer time. They are planning to extend this to the Sakhalin-Japanese arc region. First arrival times of P waves only were used in the solution. They have plans to extend this to S waves but because of the uncertainties in exact arrival times of the S waves, this extension presents some problems.

Other problems mentioned briefly included transmission of soundwaves through the ocean, and investigation of the possibility of using light rays for studying seismic velocity distribution by making models with variable refractive index materials and using these to simulate the seismic situation. The relation between the light waves and the seismic waves is being investigated mathematically. I was given some volumes of papers published by the Institute, mostly in Russian, and one volume of papers published by Springer Verlag in English, which includes papers on some of the problems which were discussed with me.

Use of transverse waves in seismic prospecting (IGG)

Dr Trogubov gave a description of the use of S waves in seismological prospecting. These are generated in one method by drilling a hole, detonating an explosion to make a cavity 1 to 2 m in diameter, and then drilling holes on either side of this and detonating explosions at the base of these holes adjacent to the cavity; this creates an asymmetrical stress distribution favourable for generating S waves. By using the holes on either side of the cavity the direction of first motion of S waves is reversed in each explosion and thus by subtracting the two seismograms obtained the amplitude of the S waves is doubled and that of the P waves is cancelled. In a further development the S waves are generated by making a small trench about 1-2 m deep and less than 1 m wide. The explosives are attached to the side of the trench, which may be up to 100 m long, and detonated alternatively on each side of the trench to obtain the reverse directions of the S waves. In a further development still, two parallel trenches each 10 cm wide are dug. Many studies are being made of the optimum dimensions and separation of the trenches, and some graphs which I saw indicated that a separation of about 20-30 cm seemed to be the optimum. Waves from these explosions are recorded to depths as much as several kilometres, so I am informed.

Advantages of using S waves are said to be a better time resolution on account of the greater time involved for travel of the seismic waves, assuming the same resolution of time at the receiving station. This applies only to phase correlations and not to absolute travel times as the S waves do not have as sudden a commencement as P waves. Also S waves are said to be valuable in detecting the point of a wedge. In some cases the depths obtained from S waves differ from those obtained from P waves. This is not the normal situation and the reasons for it depend on the circumstances in particular cases. The properties of the material may also be inferred from the ratio of the S and P wave velocities. In some records I was shown the cancellation of P waves was very nearly complete.

The SV waves are noticeably slower than the SH waves indicating anisotropy, which was believed to be mainly in the vertical direction as distinct from horizontal directions.

Deep seismic sounding (IGG)

Prof. Puzyrev and Dr Krylov, both of whom had been at the Rift Zone Symposium at Irkutsk and had just returned, described to me their work in the Baikal rift zone, in which they have done many more traverses than when I previously visited Novosibirsk in 1971. Work has apparently currently ceased in the West Siberian platform, and all the efforts at present are being concentrated within the Baikal rift zone.

They believe there is a zone of low mantle density under the lake and extending to the northeast. There is a step near the western edge of the lake at depth in topography of the Moho, and also there appears to be a change in character proceeding along the length of the lake. I was given reprints of this work and also a description of their methods in Russian. This is in the form of a paperback book which appears to cover quite a general description of the method, the apparatus, methods of analysis and identification of various arrivals, together with some examples of geological interpretation.

I also asked about the Antarctic work in the Lambert Glacier region, in which I had heard that the Siberian Institute was involved. I was shown a cross-section which was said to be the final interpretation of these data, and arrangements are now being made for its publication. A short note on the preliminary results has already been published in Russian by the Division of Arctic and Antarctic Research at Leningrad. This was in a general report on Antarctic work and was probably not widely distributed; however the cross-section which I was shown was said to supersede this preliminary report. The main features seems to be an uplift of something like 3-5 km in the Moho depth underneath the area of the glacier itself. On the east of the glacier there appeared to be three main crustal layers and to the west there were two crustal layers. Velocities did not exceed about 6.5 km/s throughout the crust.

Marine seismology (IPE)

Dr Tulina, one of Kozminskaya's Group, discussed seismic (mainly refraction) measurements. The area discussed was the Eastern Continental margin of USSR, and they have carried out many traverses in this area. I was shown many typical seismograms in which both refraction and wide angle reflection events were marked, and the very different characters of the seismograms in the oceanic crust, in the continental crust, and in the marginal region were pointed out.

In some places the transition seems to be gradual; in other places there is a distinct jump in the records with first arrivals being about 4 s later to the continental side of the apparent discontinuity. This has been mapped by shots at various distances, by overlapping spreads, and on several adjacent traverses; it appears to be a definite feature.

Shots used in the sea work originally (up till 1964) were depth charges of about 200 kilograms. Shots on some of the more recent records were up to about 5 tonnes. Information is recorded up to perhaps 400 or 500 kilometres. Some work has been done with shooting at sea and recording on land, particularly in the region near Vladivostock. The methods used are said to be a development of those of Gamburtsev as described in his book published about 1950. Ocean bottom seismometers are coming into use.

Their group does virtually no work on land now, although they used to; some work has been carried out recently by the Ukrainian Division of the Institute of the Academy in India, co-operatively with the Indians in the region of the Pamir Mountains. I showed her the profile of the geotraverse, along the West Australian shield including reflections and refraction interpretation, and she commented on the different pattern apparent in the seismograms in various zones, both changes in depth and along the traverse.

## GRAVITY

### Mathematical interpretation of potential data

Prof. Strakhov of the Mathematical Geophysical Interpretation Group explained that their research at present is devoted to three main lines. One of these is the general aspects of the theory of interpretation of potential fields, particularly with relation to uniqueness and stability of solutions; the second is in relation to numerical methods of solving equations; and the third is methods of concrete interpretation in definite geological situations, both in relation to ore bodies and general structural problems of the Earth's crust. Much of their work has been published in the journal Physics of the Solid Earth.

One of the more recent papers, which was in no. 4 of the 1975 volume, concerns establishing a body of somewhat arbitrary shape and fitting an anomaly by translating and/or rotating this body without changing its shape. The shape of the body is presumably determined by geological conditions where one might expect say an ore body to be a certain shape in view of the geological structure of the region. The computation is done automatically; the example given in the paper which he showed me was a case of a rectangle, but the method could be applied to a body of irregular shape.

In relation to the problem of non-uniqueness of potential field interpretation, one approach used is to determine the facts which can definitely be ascertained about a body such as its total mass, centre of mass, and so on, and then consider the other parameters describing the body and their possible variations within reasonable limits set by knowledge of the physical and geological properties. For a body of anticlinal shape it is shown there is a high degree of non-uniqueness in that two parameters can be used in describing the shape of the top surface of the body, and if these are chosen appropriately both of them can be varied without changing the resulting anomaly. Another case of non-uniqueness described was an asymmetrical body with a hole in it which gives the same effect as a point mass or a sphere. This body can be rotated about its axis without changing the resulting gravity anomaly. Other families of oval-shaped curves were shown which gave the same effect as a concentrated line-mass with variable distribution of density along its length.

An interpretation of marine magnetic anomalies may convert the magnetization of the body into a complex number with the real part equal to the horizontal component and the imaginary part equal to the vertical component of magnetization intensity. He claims that a solution can only be obtained for the part of the Fourier transform for which the frequency is greater than 0, and not for the part for which frequency is less than 0. This leaves of course a high degree of ambiguity in the solution unless the intensity has a vertical component only. The methods used apply only to flat layers, and the thickness of the layer is in general indeterminate. If topography were allowed on the top or bottom surface the ambiguity would become even greater.

Their methods are based on minimization of the least squares norm, but he considers that this is not necessarily the most appropriate in all cases, and believes that geophysicists should pay more attention to choosing the appropriate norm for minimization.

<u>Institute of Geology and Geophysics, Novosibirsk</u>

Dr Ladinin gave a general talk on the gravity investigations of the Institute, firstly in relation to gravity variations with time. Earth tidal recordings are similar to those at Moscow. Secular variation measurements in the Lake Baikal region have shown no changes greater than 2 or 3 microgals per year. This appears to contradict information on my previous visit (1971), when it was said that changes of 0.15 milligal had been measured over a period of 4 or 5 years.

Isostasy and density variations within the upper mantle were also studied. It was found by comparison with seismic determinations of depth that the Altai mountain region and the mountains in general in the area studied were about 90 percent compensated; in other words, the roots of the mountains were less than would be expected from the topography. On the other hand, in the platform areas the compensation appeared to be virtually complete. A zone of low mantle density was found under the Lake Baikal area, and this continued northeastwards and then northwards across Asia; also a high-velocity belt was found roughly under the centre of the West Siberian platform.

Shternberg Astronomical Institute

I had discussions with Prof. Grushinsky of the Shternberg Astronomical Institute, and Dr Sazhina of the Ministry of Geology. He has compiled all available gravity data in Antarctica and has submitted for publication in map form various presentations of Bouguer and free-air anomalies. He showed me a proof copy of a compilation of free-air means of $1^o$ squares. He is still anxious to receive any available data from the Antarctic or Australian regions, and they have plans of publishing a revised version of the four-sheet map of the Australasian area. I told them of our plans for publishing a gravity map of Australia in 1976 and he said they would wait publication of this map, but as their map covered a rather larger area they would still proceed with their revised edition. He gave me a topographic map of Antarctica and surrounding oceans, which extends as far as southern Australia, and shows some very interesting transverse features in the mid-ocean ridge just south of the Great Australian Bight. He also gave me a gravity map of Africa which he and Sazhina had prepared. This is in two variants, 5 sheets each variant.

## GEOMAGNETISM

IZMIRAN, Moscow

Izmiran, the Institute of Terrestial Magnetism, Ionosphere and Radio Wave Propogation, is at Krasnaya Prakha, about 40 km from Moscow. This is close to the earth tidal station which I visited previously. I met Prof. Pushkov and Dr Vasiliev among others.

Prof. Pushkov explained that their work was divided into three main branches - firstly, variations in time of the geomagnetic field; secondly, variations in space of the geomagnetic field; and thirdly, the effect of deep conductivity. Much of their work, of course, is related to the upper atmosphere, and particularly the first group (variations with time).

Prof. Pushkov seemed unaware of the item No. 9 on the original list of proposals for Soviet/Australian scientific co-operation, a proposal to site several geomagnetic observatories in Australia along a geomagnetic meridian which also passes through observatories in Russia, and was unable to offer any comments on this proposal such as the needs for siting, etc. However he gave me some reprints on the problem of deep mantle conductivity studies in general, and in particular one by Berdichevsky and several other authors written in English, which discusses the problem in very general terms. He also gave me many reprints, mostly in Russian, discussing the problem of secular variation of the Earth's magnetic field, and a few papers on magnetic anomalies.

Dr Vasiliev is their expert on ionospheric sounding. They have several ionosondes in a large hut. They appeared to be fairly standard type equipment, rather bulky, but apparently give good results. He showed me an atlas of ionograms of various types to help in identifying and reporting. I also inspected the cosmic ray receiving apparatus, two components, one for detecting neutrons and the other one for mesons.

IZMIRAN, Leningrad

At Izmiran Leningrad division I met Dr Ivanov, Deputy Director, whom I recalled meeting on the magnetic ship Zarya in Melbourne in 1957 or 1958, and Dr Tyasto and Dr Kolisova.

They prepare magnetic charts for the whole world and showed me their charts for the epoch 1970 in H, D, Z, & F. They are based on all available data from observatories, repeat stations and other stations on land, and also marine data. They use the secular variation as derived by Izmiran in Moscow.

They make spherical harmonic representations of the field to the 11th degree. They have tried calculating as far as the 21st or 22nd degree, studied the pattern of errors obtained, and have decided that the 11th degree is the most appropriate in terms of a reasonable representation of the data. They compared their method with that of Cain, who produced a map to eighth degree only, and considered that this did not go far enough. They have also made detailed studies of the autocorrelation functions and power spectrum of magnetic anomalies at sea and found some interesting variations in the pattern for deep ocean basins and marginal seas, areas near mid-ocean ridges, trenches, and continental shelves. They hope to find some pattern in the autocorrelation functions and power spectrums which would be typical of oceans as a whole, but the variations shown for the various areas seem to indicate that this is unlikely to be achieved. They have not progressed as far with similar studies for magnetic anomalies on land.

Ivanov has expressed some doubt about the sea-floor spreading hypothesis based on magnetic anomalies, in so far as these are based mainly on total force measurements only and because of the very large non-uniqueness in magnetic interpretation.

They offered to post me reprints and publications of their work, which I accepted. They were very interested in our marine coverage of the area surrounding Australia as well as the surveys on land and would like to receive data on these whenever available, either through the world data centre in Moscow or with copies sent directly to them. I explained that the present maps available were preliminary for the marine data.

## ANTARCTIC GEOLOGY AND GEOPHYSICS

### ANTARCTIC

At the Institute of Arctic and Antarctic Research, the Director Tureshnikov explained that the Institute organized the surveys and that the geology was done by officers of the Institute of Arctic Geology, much in the same way as BMR provides geologists for Australian Antarctic Expeditions operated by the Antarctic Division. His own interests are in oceanology and his Institute provides such services as transport, meteorological advice, etc.

In relation to potential assistance to ANARE, the weather reports from Molodezhnaya are telexed daily to Melbourne and other world data centres, and of course are available as are also reports on sea ice and similar conditions. He said that further advice on particular conditions would be readily available on request by radio. There is a possible small difficulty that they are unlikely to have anybody who speaks fluent English. In general the ice is fast for some distance from Molodezhnaya till late February or March, and the normal way of re-supplying the station is by helicopter from the ship at the edge of the ice shelf. A visit by the Australian relief ship would be welcome at any time we wished to make the visit. Use of airport facilities would also be readily available but there are landing facilities only for aircraft fitted with skis, or of course helicopters. Information was given on possible camp sites, landing spots for helicopters and general climatic conditions in the Enderby Land area. I sketched this and wrote brief notes on a BMR map, which was returned to the Geological Branch.

They will not be carrying out any geological surveys in Enderby Land or anywhere from Molodezhnaya next year or in the foreseeable future. They have shifted their efforts to the Weddel Sea area and will be co-operating with other countries in that area. They have completely mapped Enderby Land at a reconnaissance scale and showed me a large coloured map of the area, and also a comprehensive geological map of the Prince Charles Mountains regions together with detailed profiles over a number of outcrops, in particular the Stinear Nunataks, Macaulay Mountains, and two other areas. They also provided me with a copy of a rather large bound volume which describes the rocks of the crystalline basement of Antarctica and includes a map of Enderby Land, which is very similar to, but on a smaller scale than, the hand-coloured map which I was shown. This book was published in 1971 and apparently modifications to the map since that date have been only minor. Many of their results have been published in the journal Arctic and Antarctic published by the Institute, in Russian with English titles and abstracts. The age of the rocks in Enderby Land was said to be the oldest in the world, as much as 4000 million years old, based on uranium/lead age determinations. The geological work was described by Kamenov, Kuiperov, and a third scientist.

The latter also described gravity and aeromagnetic work in the Prince Charles Mountains area, in which some very interesting results were apparently obtained. He also showed me a crustal cross-section across the Lambert Glacier, which was the preliminary version referred to by the scientists at Novosibirsk. This has been published in Russian in another journal called Antarctica. They also have aeromagnetic and gravity results in Enderby Land region. The aeromagnetic results are being processed, and as no geophysicist was present in Leningrad at the moment they could give me no description of these. It is expected that they may be published in perhaps one or two years. The gravity data may well be available at the World Data Centre - I did not get specific information on this point. Grushinsky has been collecting all Antarctic gravity data for the purposes of compilation of his map through the WDC.

## APPENDIX 2

## SWEDISH DEFENCE RESEARCH INSTITUTE

### Discrimination between earthquakes and explosions

I visited the office of the Swedish Defence Research Institute and spoke with Dr Dahlman. He explained the history of international agreements on nuclear disarmament and their role in contributing to the problem of detecting nuclear explosions and distinguishing them from earthquakes. Some of the discriminants used in identification include:

(1) the location of the event, consideration of whether it is in a country or at a site likely to be used as a nuclear testing site or for use of nuclear explosives for peaceful purposes.

(2) an estimate of the depth of the event if possible; naturally anything deeper than say 5 or 10, certainly 10 kilometres, would be an earthquake.

(3) the ratio of MB to MS magnitudes, which has been used for some time but does not always give a clear answer to the question.

(4) what he calls an index of complexity, that is to say, the ratio of amplitude in the initial part of the P wave train to the latter part or coda. As an example, he showed me cases where this had been defined as the integral of the energy squared during the first two seconds of the seismogram of an earthquake as compared with the same integral over the time interval between two and 25 seconds.

(5) the spectrum of the P wave train; in general it is supposed that explosions have a somewhat higher frequency than the natural earthquakes, although he showed me examples where this is certainly not so.

In general the events in Russia, as recorded at Hagfors Observatory in Sweden, show rather a sharper initial P wave with a small coda and higher frequency for explosions, but for events in USA this is certainly not so. The frequency recorded at Hagfors for the United States events is much the same as that for earthquakes. The coda of the P wave train is, if anything, more complex and energetic than that for earthquakes, and contains some low-frequency energy, say 20 s or so, after the initial arrivals. The transition path between Russia and Sweden seems to have very high Q and little energy is lost, whereas between USA and Sweden there is definitely absorption occurring.

In general a reasonably positive identification can be made only by using all these parameters, or all that can be determined for a given event, and the certainty of determination is believed to be something of the order of 1 percent; in other words 1 percent of events identified as nuclear explosions may be false alarms, and probably 1 percent of events classified as earthquakes may turn out not to be. They take account for example of all announced nuclear explosions; these are mostly from the USA, which does all its testing at the Nevada testing site and announces some, but not all. According to the Swedish estimates the announced nuclear events in USA are about 50 percent of the total.

In Russia no events are announced, whether they are used for military testing purposes or for peaceful purposes. Apparently very many Russian explosions are used for peaceful purposes, such as construction of channels for diversion of rivers and possibly harbour construction and various other objectives. The Russians have described some of their nuclear explosions for peaceful purposes and their effects, objectives and so on, but they do not give the time nor the places or these nuclear events. From the descriptions given and from the identified nuclear events, the Swedes have, they believe, positively identified some of the described events, and correlated them with the detected nuclear events. They believe that events in Russia can now be identified to as low as about 1-3 kilotons, depending somewhat on the location, etc.

The coverage of their network is good for both USSR and USA, India, China, the Sahara Desert, but the French testing sites in the Pacific lie within the range of $100^{\circ}$ to $140^{\circ}$ where P-wave shadow prevents any energy from being recorded; this is the main reason for their interest in information from Southern Hemisphere stations, such as Australia and New Zealand. They can, of course, get copies of seismograms and reports of events from USA and other western countries quite readily, but from USSR, while in principle there is no objection to giving such information, in practice it cannot be relied on being provided as requested.

They have made very detailed studies of the nature of explosions and earthquakes, particularly those from the same regions, and where an event can be positively identified this is used as a sort of a calibration for the particular site, and other events may be compared with this. Also, statistical distributions of the various parameters are analysed; the distributions of the parameters for explosions and earthquakes may show different peaks, but the parameters for many events from a particular area may overlap in an intermediate zone where positive identification cannot be made on the basis of any one given parameter. Sometimes by plotting one parameter against another the two groups of earthquakes and explosions may fall more readily into distinct areas of the graph. This is done not only for pairs of parameters, but for multidimensional combinations of parameters by use of computers. They use a computer program routinely to locate practically every event recorded on their array, and do not accept the US determinations necessarily or the ISC lists; in any case they do not wish to wait for these lists to be distributed. They also use information from arrays such as Eskdalemuir, Yellowknife, etc. in combination with single station records for location in a way which the US do not.

Dr Israelson explained in more detail some of the methods used for identification (and a set of reports on these will be posted to me), and Dr Slunga explained the methods used for estimation of depth of earthquakes. They have found that normally depths are estimated by NOAA only for approximately 10 to 15 percent of all earthquakes; however a study has shown that if detailed examination is made of the records the percentage may be increased very considerably, especially in favourable situations where many local seismic recordings are available, by using the standard surface reflection methods. In one instance in Japan, for example, it was found that the number of earthquakes for which depths could be allocated could be increased to about 50 percent. This was done by asking 8 seismologists to examine the records and try and pick the later events. They were not accepted as events unless at least four of the seismologists identified the same event, and the identification as surface reflections depended on their identification at several stations of the Japanese network and not on any one station.

Another method used is to study the travel times, which of course are different for events at different depths, particularly in the range from $20^{o}$ to $90^{o}$, and have once again shown that detailed study, including determination of particular travel time curves for given regions, helps to improve the number of depths which can be determined very considerably.

Within this range they fit the travel time curve with a quadratic equation for each given area $A + B\Delta + C\Delta^2$; B and C terms are assumed to be much the same for a given region of seismicity within perhaps a few degrees, but the A term is considered to be variable for almost every source.

Another method tried is to study the variations in the spectra of the P waves. Generally the tendency is to work on P waves rather than S or surface waves because of the much greater number of P waves reported, and also the rather more definite identification of the events, times of arrivals, etc.

They have an in-house computer, a mini-computer so called, a PDP 15 with disc storage for 4 megawords, tape drive attachment, and a graphic display unit. The latter is fairly new, and programs they have at the moment for display of seismograms include facilities for changing either time or amplitude scales, shifting the seismograms, lining up one or more seismograms and simple operations such as this. They are developing further programs for adding and subtracting time-shifted seismograms, power spectrum analysis, cross-correlation, and similar procedures to help in inter-active analysis. They also have a library of events, and to help in identification of a particular event they can call up one or more events from a similar area and make comparions. They also have access to a larger computer (a 360/75) but they find that this is unsatisfactory - slow time of turn around, unsatisfactory tape-handling procedures, and many other complaints which sounded familiar.

<u>Hagfors Observatory</u>

Hagfors Observatory is situated about 500 km west of Stockholm, close to the Norwegian border, and about 1½ hours drive north of Karlstad. The site was chosen after quite extensive noise testing done in conjunction with Prof. Bath of Uppsala, and it was found that there was substantial reduction in noise level on moving inland towards the spine of the Scandinavian Peninsula.

The complete network consists of three stations, forming a triangle with sides approximately 30-50 km, the other two stations being to the north and northeast of Hagfors. At each site there are five vertical seismographs set out in a circle of about 1 km diameter. The reason for choosing this was based on the pattern of the noise and the signals which it was wished to detect. It was found that the noise consisted of Rayleigh waves presumably, with velocities between say 3 and 5 km/s, whereas the teleseismic signals had velocities of about 8-12 km/s. The teleseismic signal spectrum peaked at somewhere about three to five hertz. The noise had a peak in the 6-10 or 12 sec period range and another peak also in the 3-5 hertz range. The choice of seismometers and galvanometer plus electronic filtering got rid of the low-frequency noise spectrum satisfactorily but of course did not eliminate the higher-frequency component. Much higher-frequency noise in the 20-30 hertz range is also eliminated.

Studies were also made of the coherence of the noise and seismic signals; these showed that coherence decreased substantially over a few km; at 10 km, there was virtually no coherence at all. The method chosen to separate the signal from the noise is based on the fact that with a velocity of 10 km per sec and frequency of 3 or 4 hertz the signals should be in phase over a distance of about 1 km, which corresponds to 0.1 s and about ¼ wave length; whereas for the noise the same distance takes about 0.3 s and the spacing covers virtually a complete wavelength. Thus by summing the results from all five seismometers the noise would be largely eliminated, while a signal would be enchanced.

Each group of seismometers, with a very narrow band pass filtering, was used for detection of events. If an event is detected, that is, if the summed signal-to-noise ratio exceeds a certain threshold (usually about 3 : 1) then an event is declared; this can be declared by any one of the three stations. A continuously recording tape loop records everything and wipes after about 90 s, but after an event is detected by any one of the seismometers the signal is transferred to a permanent tape which runs for about 3 minutes and records on all the channels.

One seismometer at each site is in a borehole drilled about 10 m into bedrock; the other four are Geotech standard vertical seismometers and are seated on the bedrock in steel chambers sealed to the bedrock and at the entrance at the top. This prevents the instruments being affected by pressure variations, and as they are buried at a depth of a couple of metres in the loose moraine they are also subject to only very small temperature variations, about 0.1$^{o}$C during the day.

At Hagfors there are also horizontal component east-west and north-south short-period seismometers. At each station there is a long-period Z seismometer and at Hagfors also long-period horizontal seismometers. There is also a vertical seismometer at Kalyx, about 800 km to the north or northeast of Hagfors near the Finnish border; this is rather experimental at the moment. Signals from the two other seismometers in the triangle are transmitted by microwave link to Hagfors. The two nearest stations SPP and ALL are serviced by the Hagfors Observatory staff, which consists of about 5 people, and are visited about once a month. The Kalyx Observatory is connected by telephone line to Stockholm and is serviced from there by aircraft travel.

Dahlman claims that because of the lack of coherence for seismic signals comparatively large arrays such as those at Norsar, Eskdalemuir, Yellowknife, Warramunga, etc. are largely a waste of effort for the frequency range considered here as the theoretical increase in signal-to-noise ratio is simply not obtained; however, coherence is much greater for signals with frequency in the range 0.1 - 1 hertz and lower, and the arrays do offer advantages in studying such waves. When an event is detected the recordings are made with a somewhat wider band pass filter than for the detection arrangement. As the signals are recorded almost purely for the purposes of identification, and as this is based almost entirely on the P wave train, records are made for about 3 minutes for each event. The high speed of the recordings uses up a lot of paper chart and they are anxious to eliminate unnecessary recording. Slower recordings are also made at 2 cm/minute or thereabouts; a fast recording is about 2 cm/s, and times down to 0-01 s can be resolved on this.

Altogether about 40 channels are recorded, including a channel from each of the five vertical short period seismometers at each of three sites, the horizontal and long period seismometers, and a microbarograph. These are converted to digital form and stored on tape. The analogue charts have one short period and one long period channel from each of the sites, together with time information and so on. The times of arrival of the event as estimated from these charts are scaled visually, and these are punched into computer compatible form and fed into a computer on the spot which calculates the azimuth of the event. Also with use of the horizontal component times, the distance is calculated, and the maximum amplitude of the signal for each site, and the period of the wave at the maximum amplitude, are scaled.

There is a small computer on site with tape recording attachment which is largely devoted to real time processing of the recording, i.e. converting to digital form and storing on tape. The information from each event is telexed to the computer at Stockholm, where azimuths, distance etc are computed and fed back printed on the telex. During the processing of the records and examination of output of the telex, obvious false alarms and other apparent events which do not conform to patterns used for recognizing real events are eliminated, and ultimately the revised list is typed out by the teletype in the form of a bulletin which is issued within two days of the event. Further identification of the events as earthquakes or explosions takes place at Stockholm.

In addition to the regular daily bulletins, special information bulletins are published on interesting events showing seismograms for typical explosions and earthquakes in selected areas or new events, such as Indian and Chinese nuclear explosions. They are published about twice a year. The series may be discontinued when a reasonably representative set of events has been reported. They show seismograms, power spectrum analysis and description of locations, characteristics etc.

In the side of the hill near the observatory buildings there is a tunnel with about 10 chambers opening off it and these are available for special projects. These include a set of Russian long period seismometers, a tilt meter set up by another Swedish agency, which is a horizontal pendulum quartz movement type I gather, with mercury columns which are used in some way to restore the pendulums to the null position; this is supposed to give some advantage over the normal quartz pendulum type of recording. The tunnel itself and each of the chambers have doors which are intended to seal the pressure variations off, or at least to delay the effects of outside pressure variations. There is much water flowing through the rocks and much of the floor is quite damp. The chambers are available to research workers from other groups who may wish to install equipment, or for experimental purposes as required by the observatory staff itself.

Power is derived from the mains but as it is found that surges in the mains occur frequently and interfere with the equipment and particularly the computer, the mains power is used to charge a large bank of batteries, which in turn drives a tuning fork controlled oscillator, which keeps a very accurate 50 hertz and a very even voltage output. In the event of power failure, the batteries operate the station for 30 sec, during which time a generator is started up and carries the load until power is restored. They have much trouble with lightning strikes and have installed sophisticated lightning protector devices, but in the event of a direct strike on the antenna the output stages and transformers and amplifiers and the seismometers are all burnt out. This has happened on two or three occasions.

The observatory buildings are about 5 km from the town of Hagfors where most of the staff reside, and about 100 km from the city of Karlstad where Dahlman and I stayed the night on the way to the observatory. Staff from Stockholm are encouraged to spend about 1 month per year each at Hagfors to maintain contact, and conversely the Hagfors staff have periods in the office at Stockholm.

## APPENDIX 3

### List of Abbreviations Used

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| AARI | Arctic and Antarctic Research Institute, Leningrad. |
| ANU | Australian National University, Canberra. |
| BMR | Bureau of Mineral Resources, Geology and Geophysics, Canberra. |
| IAG | International Association of Geodesy |
| IAGA | International Association of Geomagnetism and Aeronomy. |
| IASPEI | International Association of Seismology and Physics of the Earth's Interior. |
| IGG | Institute of Geology and Geophysics, Siberian Division of Academy of Sciences, Novosibirsk. |
| IGRF | International Geomagnetic Reference Field. |
| IPE | Institute of Physics of the Earth, Academy of Sciences, Moscow. |
| ISS | International Seismological Summary. |
| IUGG | International Union of Geodesy and Geophysics. |
| IZMIRAN | Institute of Terrestrial Magnetism, the Ionosphere, and Propagation of Radio Waves, Academy of Sciences, Moscow, Leningrad, etc. |
| JOIDES | Joint Oceanographic Institutions' Deep Earth Sampling |
| NCC | Novosibirsk Computing Centre, Mathematical Institute, Siberian Division of the Academy of Sciences. |
| SCAR | Scientific Committee for Antarctic Research. |
| WDC | World Data Centre. |