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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORDS 1960 No. 100

REPORT ON VISITS TO OVERSEAS COUNTRIES, 1959

by

J.C. Dooley

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C O N T E N T S

<u>LIST OF DOCUMENTS RECEIVED</u>

OTHER PUBLISHED REFERENCES

ILLUSTRATIONS

LIST OF INSTITUTIONS VISITED, WITH ABBREVIATIONS

United Kingdom

CU	Cambridge University, Department of Geodesy and Geophysics
LIC	London Imperial College, Kensington
LTI	Liverpool Tidal Institute, Bidston Observatory, Birkenhead
MI	Meteorological Institute, Air Ministry, London, Eskdalemuir, Edinburgh, Kew
NPL	National Physical Laboratory, Teddington
OGI	Overseas Geological Institute, Kensington
RAE	Royal Aircraft Establishment, Farnborough
RO	Royal Observatory, Herstmonceux
UKGS	U.K. Geological Survey, Kensington

Holland

BPM	Bataafsche Petroleum Matschaappy (Royal Dutch Shell), The Hague
KNMI	Koninklijk Nederlands Meteorologisch Institut, de Bilt

Belgium

IRM	Institut Royal Meteorologique de Belgique, Uccle (Brussels) and Dourbes

France

CGG	Compagnie Générale de Géophysique, Paris
IPG	Institut de Physique du Globe, Paris, Chambon-la-Forêt, Parc St. Maur.

Canada

DO	Dominion Observatory, Ottawa

United States

GRD	Gulf Research and Development, Pittsburgh
LGO	Lamont Geological Observatory, Columbia University, Pallisades (New York)
NASA	National Aeromautics and Space Administration, Washington
OSU	Ohio State University, Columbus, Ohio
PSL	Pasadena Seismological Laboratory, California Institute of Technology, Pasadena
RC	Rand Corporation, Santa Monica
UCB	University of California, Berkely, Department of Geology
UCLA	University of California, Los Angeles
UGC	United Geophysical Corporation, Pasadena
USAMS	U.S. Army Mapping Service, Washington
USBS	U.S. Bureau of Standards, Washington
USCGS	U.S. Coast & Geodetic Survey, Washington
USGS	U.S. Geological Survey, Washington
USNHO	U.S. Naval Hydrographic Office, Washington
UW	University of Wisconsin, Department of Geology, Madison

ABSTRACT

The writer visited a number of overseas countries during August-October 1959. The chief objective of the trip was to investigate the processing of geophysical data by automatic computing machines. This objective naturally involved visits to leading centres of research in the various branches of geophysics, and the opportunity was taken to discuss more general aspects of their programmes where these were related to the Bureau's work. The principal branches of geophysics investigated were gravity, magnetism, and seismology, both in their fundamental aspects and as applied to exploration. Information was specifically sought on developments in two fields which it is intended to include in the Bureau's programme — namely, recording of earth tides, and measurements of gravity at sea.

The writer attended two scientific conferences while overseas. These were the Symposium on Rapid Magnetic Variations held by Committee No.10 of the International Association of Geomagnetism and Aeronomy, and the triennial meeting of the International Gravity Commission of the International Association of Geodesy. The writer presented a report on gravity investigations in Australia, at the latter meeting.

The bulk of this report consists of notes giving details of discussions with officers of the various institutions visited. These have been compiled from notes made immediately after each visit, and have been sorted according to subject matter into the chief branches of geophysics studied.

A list of documents received from the conferences attended and the institutions visited is also appended. These will be available in the Geophysical Branch Library. References are given also to other published papers relevant to topics discussed during the visits. Some of these have been published since the visits.

Although application of high-speed computers was the chief purpose of the trip no separate section is included on this subject. Applications were found in all branches of geophysics studied, and the details are discussed in the notes on visits to the institutions concerned.

A final section summarises some recommendations regarding the Bureau's methods and activities, particularly in relation to computer applications.

1. SYMPOSIUM ON RAPID MAGNETIC VARIATIONS

INTRODUCTION

This was held at Utrecht, Holland, from 1st - 4th September 1959. It was attended by about 40 scientists from a variety of countries. Fr. Romana was Chairman.

In the preliminary circular announcing the meeting, it was requested that formal papers should be kept to a minimum and that open discussion should predominate. However, as the number attending was about double that expected, some formality was necessary to maintain reasonable order.

Papers and discussions were almost entirely in English and French. Discussion was interpreted in these two languages by Selzer and Cardús, except that when the discussion in French became particularly animated they occasionally forgot to interpret for a while. Papers were not translated. I was able to follow the French ones only when a copy was provided.

Russian scientists did not attend the meeting, but sent their apologies, comments on the agenda, and twelve papers. These were summarised for presentation to the meeting under the relevant topics.

The symposium was divided into sessions on different topics, with an introductory paper on each. The sessions were pulsations (pc and pt) with introduction by Coulomb, earth currents (de Voogt), sudden commencements and impulses (Chapman), and solar flare effects (Veldkamp). In addition, various countries presented reports on their IGY studies. On the final day, the final form of the Atlas of Rapid Magnetic Variations was discussed.

A visit to de Bilt observatory was arranged for the evening of September 2nd.

PULSATIONS

An excellent review of the theories of pulsations was presented by Coulomb (Ref. 1.iii)(in French). These are now generally attributed to hydromagnetic oscillations in the outer atmosphere, probably in some way connected with the van Allen zones. Toroidal oscillations are the easiest to treat theoretically, but these imply a variation of period with latitude. Observations do not appear to support this (see however Obayashi and Jacobs, 1958); therefore poloidal oscillations are a more likely cause.

Giant pulsations (pg) and trains of pulsations (pt) are attributable to auroral sources, propagation to lower latitudes occurring electromagnetically. Continuous pulsations (pc) are presumably due to some form of cavity resonance, perhaps between a van Allen zone and the ionosphere. However, damping due to neutral gas should be stronger than that observed. Difficulties occur owing to lack of knowledge of the outer boundary conditions and of the temperature of the upper atmosphere.

The ultimate source of excitation is generally supposed to be solar particles, but the mechanism involved is by no means certain.

Frequent references were made during this paper to the work of J.W. Dungey (who was present). I was told that his book (Dungey, 1958) is one of the best on hydromagnetic theory. This has since been purchased for the Geophysical library.

This was followed by a summary of several of the Russian papers, presented by Fr. Cardús.

Prof. Kalashnikov's comments (Ref. 1.xv) called for more specific description of pulsations, giving period, amplitude, and duration; recording of earth currents as well as magnetic variations on the same record; the measurement of space gradients as an aid to locating sources, which he believes are numerous; correlation of phenomena with other geophysical and solar phenomena; and a permanent world net of 10 or 12 rapid-variation stations using standard equipment.

Mrs. Troitskaya's comments (Ref. 1.xvi) suggest division of pc into 3 groups, with period 5-15, 20-40, and 50-90 sec.; recognition of "transparent" days when pc occur widely; study of the fall in occurrence of pc in the polar night; relation of polar pt to other disturbances; study of "pearls" (pp), IPDP (Refs. 1, xxiii and xxiv), and microstructure of ssc and si.

Ref. 1.viii (Bolshakova, Zybin, and Maltseva) reports on pulsations at observatories Lo (68°N 35°E), Bo (58°N 39°E) and Pe (58°N 159°E). pc occur with periods 20-90 secs.; less regular oscillations with periods 2-4 min. last for several hours (generally 2-3 hrs. per day at Lo, 4-5 hrs. at Bo, and 6-8 hrs. at Pe). pc occur most frequently with periods of 20, 30, and 60 sec (about 400 hours per month each); less frequently with period 50 sec (about 100 hrs.). Diurnal variation of occurrence is claimed to correspond with local time for 20- and 30- sec pulsations, with universal time for 40 sec, no variation at 50 sec, and maximum at local noon for 60 sec. Amplitude for all periods has a maximum at noon, except at Lo which has a night maximum.

Ref. 1.x. (Kalashnikov and Zybin). The horizontal vector of magnetic variations was studied at Borok with a tripartite fluxometric installation, recording 3 components at 90mm/hr. The vector end moves generally around an elliptical path during an oscillation, with high eccentricity. In 75% of cases, the major axis lies in the NW-SE direction; it is N-S in 10%, and E-W in only 2% of cases. About 10% are approximately circular. "Western" azimuths average 38° W, and have maximum occurrence at 04 hr local time, with mean direction 59° W; and a minimum at 15 hr, at 23° W. Rotation is counter-clockwise in 60%, clockwise in 30% of cases, the remainder being linear on the average with deviations. These laws are compared with earth-current registrations. The explanation is believed to be current vortices in the ionosphere.

Ref. 1.xi (Kalashnikov and Mikhova). A study is made of the vertical component of pt, ssc and si at Bo, Lo, Pe, and Du (42° N, 44° E) and some American stations. It is found that, for Z components, Bo $<$ Du $<$ Pe $<$ Lo, whereas for H, Bo $<$ Pe $<$ Lo. The reason is not known, but may be affected by proximity of Du, Pe, and Lo to the sea.

Ref. 1.xii (Afanasieva). Pulsations with periods 30 sec to 240 sec with amplitude $>$ 1 gamma were studied at 9 observatories, for 180,000 observatory-hours. pc has a maximum at 11-14 hrs. L.T., and at a northern observatory, a secondary maximum at 05-07 hrs. This is not dependent on seasons. There is no pc at night. The "night" period is longer in winter but is independent of latitude. pc is more frequent at lower latitudes. The form does not depend on magnetic activity, but on disturbed days the time of maximum occurrence is earlier. pt has a maximum at 20-24 hrs. L.T., but no distinct maximum at northern observatories. This is independent of seasons and activity. The occurrence at time of maximum increases southwards, and pt is more frequent in winter. pc occurs on 80-90% of days, and pt on 30%. There is a connection with the daily variation of f_oF_2, but not at Leningrad. pc is explained as due to slow streams of corpuscles reacting on the highly ionised sunlit atmosphere; pt as due to corpuscular streams on ionised regions in night and morning zones at high latitudes.

Ref.1.xxvi (Dubrobskiy). At 38° N, 58° E, pc have a maximum at noon L.T. Irregular periods (20-25 sec) are more common than regular ones (15-20 sec). Occurrence is greater in summer than in winter by a factor of 1.5 to 2, and an increase of 10% on disturbed days is noticed. pt have a maximum at midnight, predominant period being 55-60 sec. pp with very irregular periods about 1-3 sec occur during storms and with aurorae. Maximum occurrence is at night.

Ref.1.xiii (Nikolsky). He claims that the night and morning maxima of pulsations in polar regions form a spiral pattern with four arms, corresponding with Störmer's theory of particle precipitation. The solar corpuscles are believed to be protons. Earlier maxima during disturbed periods are explained by higher velocities in the corpuscle stream.

Selzer described the results from French stations (Ref.1.xxi). Recordings with bar-fluxmeters were made at Chambon-la-Forêt, Bangui, Kerguelen, Dumont d'Urville, and Charcot. At mid-latitudes pulsations of 3- to 8- sec period are observed from about 22h-04hr., and then give place to normal pc, periods 10 to 45 or 50 sec. Pulsations of 0.6 to 3- sec period, duration about 20 minutes, have been observed during some storms. These "micro-pulsation storms" warrant further study. He discusses certain possible systematic errors in statistical investigations of dependence of pc on local or universal time. The sensitivity of the apparatus may affect the distribution, by recording smaller events at times when occurrences are not noticed on less sensitive apparatus. He mentioned Maynaud's (1955) J (jour, or daytime) disturbance inside the auroral zones - irregular oscillations with pseudo-periods of several minutes. Similar but much smaller disturbance occurs at lower latitudes, even at Bangui (near the equator). pc vectors are being studied; anomalous effects in Z are noticed near the oceans. pt tend to a north-south direction with lower latitudes. He quotes some examples of correlations of events at the various stations; the clearest examples of SSC have never given evidence of time differences greater than 15 seconds between the stations.

Veldkamp discussed the giant pulsations (pg) of 17th July 1958 (Ref.1.xviii). Previous investigations showed that these occur in auroral and sub-auroral zones, but not inside the auroral zone. They generally show a harmonic spectrum of one of two fundamental periods. Maximum occurrence is at 62-63° N, periods being usually 60-90 sec. Other stations may have periods of 75 or 135 sec. A regular type of pg occurs in morning hours, and an irregular type in the afternoon.

For the event under discussion, vector movement was nearly circular, and the period 70-95 sec until 0935 hr., when an si occurred; after this the period changed to 110 sec. The event was recorded between 50° and 60° geomagnetic latitude; at Va, Es, and RS, amplitude was 25 gamma. Coherence between stations could be found only for distances less than 500 km. The theory of Jacobs and Obayashi (1958) appears to account for the phenomenon, but comparisons between conjugate stations are needed to check this. Not many suitable pairs exist - Toolangi and Srednikan are one possibility.

In discussion, Bartels mentioned that pg had occurred all over the earth on 1st March 1942, for a duration of two hours with a 5-minute period, at the end of a storm. This could not be investigated at the time.

Angenheister said that maximum of shorter-period pulsations was at 09 hrs. ($7\frac{1}{2}$ sec upwards). Longer periods (up to 240 sec) occur later in the afternoon. In 1954-5, maximum activity was in longer periods; in 1956-7, in shorter periods.

Jacobs described variations in pulsations over a distance of 25 miles near the coast (Duffus et al, 1959). At the inland station X is always greater, Y nearly the same, and Z always smaller than at the coast. The ratio varies with period; from 10 sec to 200 sec., from 1.6 to 1.0 for X, 0.8 to 1.1 for Y, and 0.3 to 0.8 for Z.

Dungey pointed out the importance of the transition from predominantly oxygen ions to hydrogen ions in the atmosphere. This was formerly believed to occur at 1000 km height, but rockets showed that it was at 2000 km. This would alter the periods of hydromagnetic pulsations as calculated from various theories. Ion densities calculated from whistlers vary by a factor of 3 or 4, and one would expect pulsation periods to vary similarly. Resonance of the "cavity" with a normal mode of oscillation may not always be the cause of pulsations - a shock wave theory may apply in certain cases. Oscillations would accompany a shock-wave, but their period has not been calculated yet. If a magnetic field exists in inter-planetary space, the oscillations could arise from the sun.

Further Russian papers were summarised (Refs.1, xxiii, and xxiv). These describe the short-period oscillations with period 1 to 4 sec (usually 1-2 sec) which occur in bursts of a minute or less. Their appearance on moderately-rapid-run recorders resembles pearls on a string, and the name "pearls" has been proposed for them, with abbreviation pp. They occur in association with aurorae or with excessive ionospheric absorption. Short bursts are common in the Antarctic, and longer series in middle latitudes. Some cases are observed at one station only, some at several simultaneously. The occurrence appears to be controlled by both local and universal time. Some sequences show successive bursts with decreasing periods. These have been referred to as IPDP (intervals of pulsations with diminishing periods.) These occur simultaneously over wide areas, and are controlled by universal time.

EARTH CURRENTS

Bock described recording in Germany at speeds of 1 or 10 mm per hour. Several long lines had been used. Potential gradients ranged from 16-47 mV/m.

Grenet described the Tamanrasset recorder, using an 0.8- sec. galvanometer. Pulsations of 20-25 sec were recorded; shorter period pulsations were believed to be due to meteorological storms in equatorial regions. He has deduced from the recordings that the vertical current from ionosphere to earth is about 21 amp average for the whole globe; this figure varies with the frequency being considered. At Chambon-la-Forêt, a narrow band of pulsations at 0.6 sec is observed in the summer. The intensity increases when storms approach.

Untiedt described an instrument for recording vector earth currents directly at Göttingen. The vectors tend to lie in preferred directions, generally NW or WNW for oscillations of medium period. The seasonal variation from summer to winter is from 130° to 160°. At night the vectors follow loops rather than straight lines. The reason for the daytime direction is not known - it has been estimated that local induction could not effect the azimuth by more than about 8°.

Schlich showed some polar diagrams for pc at Charcot - the directions appeared to be random. Only a few examples of pt were recorded.

Olsen suggested that Arctic and Antarctic disturbances should be compared at the equinoxes, as conditions are asymmetrical in summer and winter.

SUDDEN COMMENCEMENTS AND IMPULSES

Chapman introduced this session with a review paper (Ref. 1.xxvii). He proposed a new classification of sc (instead of ssc); however Bartels pointed out that sc was already in use. Further instead of ssc and ssc*, he proposed sc++ or sc-+ etc., according to the initial and subsequent movements of H. (one sign would be adequate in many cases). sc+ is most common in low altitudes, sc-+ is more common in higher latitudes. si are only reported in quiet periods. Investigation of times of occurrence of sc+ showed a world variation of no more than 10 sec or so (however see Williams, 1960), and study of propagation has been hampered by lack of accuracy in the recording.

The theory of sudden commencements is of course inseparable from that of storms. Chapman referred to the function D(st), which is a function of universal time and latitude. He proposed another function D(s), which is a function also of longitude or of local time. He considers the Chapman-Ferraro theory of storms is still basically sound, though various modifications may be needed. Alfvén's theory considers the effect of a magnetic field on ionized solar streams - the Chapman-Ferraro theory is a limiting case of this for zero field. Alfvén predicts an inner auroral zone of 5° to 8° radius; this has not been tested. Singer suggests that transient belts of charged particles are formed at distances of 4-8 earth radii, with velocities about 2000 km/sec. A shock-wave in interplanetary gas is supposed to cause the sudden commencement. The theories of Dessler and Parker (1959), and Piddington (1959 and 1960), augment the Chapman-Ferraro theory with hydromagnetic transmission of disturbances through the upper atmosphere. Interplanetary gas is supposed to have a density of about 600 electrons/cc near the Earth. Possibilities of transmission through the atmosphere are wave transmission of a solar blast (supported by Gold, Jennisson), effect of a shockwave in solar gas (Singer, Akasofu), and interpenetration of solar and terrestrial gas. The mean free path is too great for the first two theories. Dessler and Parker suggest an interchange of kinetic and electrostatic energy to effect the interpretation. Piddington claims that aurorae are not due to particles entering the atmosphere. The effect of stopping the solar stream is transmitted to the earth (lower ionosphere) in a few minutes by hydromagnetic waves.

Points still needing clarification are the exact mechanism of hydromagnetic transmission, and the origin of polar e.m.f. responsible for aurorae.

SOLAR FLARE EFFECTS

Veldkamp (Ref.1.xiv) showed the current system for the sfe of 23rd March 1958, superimposed on the diurnal variation current (Sq) system from Chapman and Bartels (1940). The sfe is not a direct enhancement of Sq, as it is related to the geomagnetic equator rather than the geographic equator. Now the E-layer is controlled by the geographic equator, and the F-layer by the geomagnetic equator; therefore it seems probable that the sfe current is higher than E. He supported this by calculation of the half-value time of exponential decay as a function of ion density; he finds that the observed time (about 25 minutes) corresponds with F ionization rather than E.

Chapman and Bartels both hastened to point out that more data had shown (since publication of their book) that the Sq pattern was related to the geomagnetic equator and not the geographic. Bartels also pointed out that the time of decay could be affected by a possible exponential decay of the solar radiation. Chapman stated that enhanced conductivity along the geomagnetic equator was also present in the D and E layers.

Veldkamp's current system shows small subsidiary loops near the twilight zones, which have not been reported before. The reality of these appears doubtful as they are based on only a few stations. I pointed out that at Watheroo (which is one of the stations) currents were inhibited by induction in some directions, and this may affect the pattern, especially as the loops at the western zone are based on stations on the east coast of South America which may be similarly affected. The reality of these should be tested by investigating sfe occurring at various universal times.

In discussion, Bartels pointed out that there is an almost 1 : 1 correspondence between solar flares and ssc about one day later. Flares on about half the area of the sun's disc are effective in producing storms.

MISCELLANEOUS

Harris reported on the U.S. Army Signal Corps installation of two loops, in New Jersey and Arizona, each with area 26 square miles and two turns. (Berthold, Harris and Hope, 1960). An advantage of a large area is comparative reduction of artificial noise, as this is more or less random. Micropulsations and sudden commencements have been studied. Agreement within 2-3 sec is claimed for the two stations. On 17th August 1958, 0140 hr UT, he claimed that the time interval between recording of a ssc at the two stations was measured as 2 seconds. (From the records shown, the "sudden" commencements appeared very gradual at the recording speed used, and I would not like to pick the beginning with that accuracy). This was confirmed by correlation of the oscillations 20 minutes after the ssc.

Selzer had with him fluxmeter records of the same ssc at Chambon-la-Forêt and Charcot. At Chambon the event was simultaneous with the U.S. recordings within 1 or 2 sec. At Charcot the event appeared to be about one minute later.

Miss Hutton discussed earth current records obtained at Ghana. The occurrence of pc(?) had a maximum at 20 hr local time. She discussed the possibility that pulsations were more or less universally present in the upper atmosphere, but were screened at certain times by the ionosphere.

DECISIONS ON METHODS OF REPORTING

For ssc, the direction of movement is to be taken separately as the chief movement for each component.

It was decided to adopt the "pearls" (pp); these to be reported on separate sheets, if possible from the beginning of IGY. Periods to be in the range 1-5 sec. Some members considered that these were probably different effects in storms and in quiet periods.

It was decided to ask for sample reports on other suggested phenomena for a period of a few months as a trial.

pg should have a long period (>60 sec) and should be very regular.

If observatories can give times of ssc recorded during IGY with accuracy of better than one minute, they are urged to do so.

Selzer suggested that sensitivity of magnetographs should be raised rather than lowered during storms, to enable study of fine structure.

Bartels on behalf of Committee No.9, said that it is not necessary for K-indices to be scaled at every observatory where spacing was close (e.g. Göttingen does not scale them!). Also they are not essential at equatorial stations, where mean hourly values are more important. (However in a recent circular, he appears to have changed his views, as the result of a study of K-indices by Mayaud). Q-indices were proving valuable, but because of work involved he had thought of specifying preferred periods where observatories found difficulty in completing the work. I said we would welcome any reduction in the work, but he said that the Australian observatories should scale Q-indices for the full period, as they were particularly valuable because of their remoteness from other stations. No decision has been made to continue these after IGY.

Romana and Cardús commented on the large variation in number of events reported, in some cases by observatories close to each other (Ref. 1.iv). They have developed an informal technique of giving more weight to those who report least, but would appreciate more uniformity. I asked how the Australian reporting stood - they said very reliable in that anything reported was definitely an event, but if anything too few events were probably reported. Ref.1.iv quotes Toolangi as reporting the minimum number of psc in one year - 9 only; the maximum was nearly 300.

A general discussion on the number of events followed - it was felt that the number published is too many for anyone to use completely. However most suggestions for cutting this down seemed to be open to some objection.

ATLAS OF RAPID VARIATIONS

It was decided to use the provisional atlas as a guide, but to collect real examples, and to use examples from polar and equatorial zones as well as middle latitude. Each phenomenon would be allotted to a different organisation, who would have the task of collecting records, selecting suitable ones, and compiling a section of the atlas.

Dates were selected on which suitable examples of the phenomena had occurred.

I suggested 23-10-57 for bays in the Pacific area, as four were recorded at our observatories on that day (although not all reported by all observatories), and the Japanese supported this. It was interesting to note that when pt was being discussed, the first date suggested by Europeans and Americans was the same day - apparently this is an example of a general connection between bays on one side of the world and pt on the other.

2. REPORT ON MEETING OF INTERNATIONAL GRAVITY COMMISSION AT PARIS, SEPTEMBER 1959

INTRODUCTION

This meeting has been described recently in the Geophysical Journal, Vol.3, p.121 (author not stated). As it seems unnecessary to cover the same ground again, the present report will be confined to discussion of various aspects which I found of interest and matters relating to the Australian programme of gravity investigations.

The meeting was attended by about 80 scientists representing 25 nations. These, and several other countries, presented national reports and in many cases additional papers on relevant subjects. Also, reports of the relevant Special Study Groups of the International Association of Geodesy were presented. Russian scientists were conspicuous by their absence, and they did not send any reports or papers to the meeting.

It was proposed that a series of summary reports and discussion should take place during the first two days of the meeting and then the meeting should break up into Study Groups which would discuss their topics concurrently in more detail. However, as many of the participants (including myself) were interested in several topics, it was decided to hold the Study Group meetings sequentially. Thus they tended to be largely continuations of the original discussions. Resolutions were framed and adopted on the last day of the meeting. These have been published in the I.U.G.G. Chronicle No.29, pp.111-119, March 1960.

INTERNATIONAL GRAVIMETRIC BUREAU

A report on the activities of the Bureau was given by Tardi, and some discussion followed on the functions of the Bureau and its relation to the Commission. It was decided that the Bureau should prepare a brief statement on the matter. This has since been distributed with a copy of the resolutions passed at the meeting, and published in I.U.G.G. Chronicle No.29.

The Commission includes one delegate from each nation, and meets triennially. Its object is to establish a world-wide homogeneous gravity network.

The Bureau is a permanent service of the International Council of Scientific Unions; its purpose is collection of gravity data and preparation of gravity maps.

It was recommended that the Bureau should publish a half-yearly bulletin giving particulars of information received with bibliography (Resolution No.1).

Dr. Coron (Ref.2b.xx) summarised the data collected from the various nations. This was compiled on a large map for display. Following our report (B.M.R. Records 1959/97), which shows Bouguer anomaly contours over the mainland, Australia was shown as completely covered by gravity surveys - in fact, the only continent shown thus. In actual fact, many of the contours are indicated by broken lines, being interpolated over large areas with no information.

Dr. Coron also referred to the descriptions of first-order stations (Ref.2b.i), national and international calibration bases, Antarctic measurements, and international ties between base stations.

She also urged the preparation of maps of mean elevations of one-degree and ten-minute squares, if possible with an accuracy of 10m. These are invaluable for calculating isostatic corrections, particularly by machine methods. It is difficult to prepare representative free-air anomaly maps in mountainous country. Bouguer maps may be more representative, but topographic corrections are rarely calculated; this should be done to 167km radius, or at least to 28.8km. BGI is proceeding with publication of Bouguer maps on a scale of 1:1,000,000, on Lambert's conical projection. This projection seems alright for fitting maps together around a band of latitude (31°N to 71°N is claimed for the projection used), but as different standard latitudes must be used for other zones there will be maps that will not fit, particularly between northern and southern hemispheres.

Isostatic maps are considered preferable, but are not used because of the work involved and because no agreement can be reached on the best system to adopt.

The Bureau was requested to prepare a report on the ways of making anomaly maps and mean height maps to cover the world. (Resolution No.2).

ABSOLUTE MEASUREMENTS

About 12 measurements are in progress, because g is used directly or indirectly in defining standards in many fields, including electrical current, temperature, and nuclear constants.

The methods used include reversible pendulums, very long pendulum, falling rod, and rise and fall methods. It seems likely that the currently used "Potsdam" system will need to be reduced by about 12 mgal; but the final figure should await completion of some measurements still in progress and the results of ties between absolute stations. Accurate ties to Potsdam are impossible at present, for political reasons.

FIRST ORDER NETWORK

The BGI has published a list of first-order stations and descriptions (Ref. 2b.i). Morelli (Ref. 2b.ii) presented a detailed report on the connections between the first-order stations. The world-wide situation is fairly good, as most loops now close to better than one milligal.

He recommended that about 20 stations (including Darwin and some Antarctic stations) should be added to the list of first-order stations; however it was decided not to add any new stations, but to try to make an early adoption of values for the existing 31 stations (Resolution No.7). It was decided to use only connections which can guarantee an accuracy of 0.5 mgal and that additional connections should be made if possible in time to adopt values at the Helsinki I.U.G.G. meeting, 1960. These ties include a pendulum connection from Melbourne or Christchurch to Buenos Aires (Resolution No.8).

CALIBRATION BASES

Kneissl (Ref. 2b.ix) and Marzahn (Ref. 2b.viii) discussed the European Calibration Line. The position here seems fairly satisfactory and it is proposed that values be adopted at the Helsinki meeting (Resolution Nos.9 and 10).

Rice reported on the North American system (Ref. 2b.xiv). There remain several discrepancies between measurements by various observers, and a considerable amount of work needs to be done before this can be finalised. (Resolution No.11).

Boulanger (U.S.S.R.) was programmed to report on the establishment of an Asian Calibration Line, but he was not present.

It was decided to establish a Far Eastern Calibration Line, with Okuda as president of the relevant study group. This may extend through Australia.

It was generally recommended that pendulum observations should be confined to intervals of about 500 mgal, and that they should be repeated several times at each station; also that different types of pendulums and different observers should be used if possible, to enable systematic errors to be detected. Adjustment of combined gravity and pendulum networks should be done by the method of Cook (1958), in which the scale factor of the gravity meter and the gravity intervals are regarded as unknowns to be determined by least-square solution of the observation equations.

REDUCTIONS

de Graaff-Hunter presented the report of the Study Group (Ref. 2b.xvi). This proposed the use of his modified Bouguer anomalies for geodetic purposes. For these a map of the world must first be produced showing elevations assuming that the topography is spread evenly around each point over a radius of 100-150 miles. The ordinary Bouguer anomalies are then corrected from actual station height to the smoothed topography height at that point.

This provoked some lively discussion. Advantages for the method claimed were :-

(a) the "model earth" with smoother topography need only be calculated once, as distinct from isostatic calculations, in which the effect of compensation of topography needs to be calculated separately for each station.

(b) it gives an anomaly which varies as smoothly as any isostatic anomaly and more smoothly than Free Air or Bouguer anomalies.

(c) it does not imply any assumption about methods of compensation.

(d) most results are presented as Bouguer anomalies and conversion would be relatively easy.

(e) the method does not move the centre of gravity of the earth or distort the geoid appreciably.

Disadvantages raised by others were :-

(a) there is no physical basis for the reduction.

(b) terrain corrections should still be calculated, and these are the greater part of the work in calculating isostatic anomalies.

(c) it is desirable to calculate isostatic anomalies in any case for geophysical studies, and these can then be used for geodetic purposes.

PENDULUM TECHNIQUES

Browne presented a very detailed account on methods and errors of pendulum observations (Ref. 2b.iv). This was discussed by the meeting as he went through the report, but unfortunately the timetable did not permit completion of this.

Discussion indicated that the following modern apparatus are capable of accuracy of 0.5 mgal or better :-

Cambridge	invar bi-pendular, magnetically compensated
Gulf	quartz bi-pendular
Askania	invar, four pendulums, magnetically compensated
Dominion Observatory	bronze, bi-pendular (Thompson, 1959)
Japanese GSI	quartz, tri-pendular

Italian Geodetic Commission	tri-pendular; several materials have been used and molybdenum appears to be the most satisfactory (Mazzon, 1957)
U.S.C.G.S.	invar, single pendulum, magnetically compensated

Several of these use pendulums about 30-40 years old, but the auxiliary equipment has been improved substantially.

GRAVITY METER TECHNIQUES

Martin (Ref. 2b.v) presented the Study Group's report. This was rather brief and referred copiously to a questionnaire, which had been distributed to various countries, asking them to inform the Study Group of their experience with errors in various types of gravity meters. Apparently not many answers were obtained. As far as I know, we did not receive the questionnaire.

Many reports followed on the experience of various observers with various gravity meters (e.g. Ref. 2b.vii). Some interesting points which I noted are given below :-

Martin stated that a variation of scale factor of Western meters had been found as 0.5 parts per 1,000 per year, and this was less than for North American meters.

Morelli had found that the rate of change of scale factors of Worden meters decreased with age of the meter. The Italians had found systematic changes of scale factor with temperature.

Dr. Graf claimed that the scale factors of Askania meters did not change after the first month; however on questioning it appeared that he did not see much of the meters after they were sold.

Rouillon (1959) discussed ties to Antarctica with a Worden meter. They are finding difficulties similar to ours. These will be discussed more fully in a later report.

Woollard said that he had found the larger type of La Coste geodetic meter (No.1) very good, but the calibration factor supplied by the makers was wrong. The small geodetic model was not as accurate as the larger one. The Worden "Master" with thermostat was good, but a jump of 2 mgal had occurred on one occasion when the meter was taken to Canada by plane and an external temperature change of 100°F had occurred on leaving the plane.

North American were now taken over by Electro-Technical Laboratories.

Thompson said that a new gravity meter with excellent characteristics had been developed by Sweet of Houston. The dimensions are 8 in. diameter and 10 in. high, and the meter is a development of the North American system.

An extensive bibliography of gravimetric techniques was distributed.

It was recommended that international gravimetric ties should be carried out within the range of calibration, that meters used should be calibrated on an official international calibration line, and that studies should be made of variations of scale factors (Resolution No.13). Publication of gravity results should show calibration base used, method and results of calibration, instrumental corrections, network and timing of observations, and closure errors (Resolution No.14).

GRAVITY MEASUREMENTS AT SEA, AND IN THE AIR

Worzel presented the Study Group report (Ref. 2b.xv). This covered measurements with sea-bottom gravimeters, measurements in submarines, and on surface ships. Brief mention was made of airborne measurements.

Measurements with the Graf sea gravity meter (Worzel, 1959) on a recent cruise of "Vema" could be made for 15% of the time only. He quoted from a report by Harrison on tests with the La Coste sea gravity meter (see also Harrison, 1959), and from one by Tsuboi on surface ship measurements in Tokyo Bay. The Japanese instrument consists of a self-maintained vibrating bifilar pendulum, severely over-damped, mounted on a gimbal platform of long period. Improvements are still being made to the stabilising system.

He recommended that ports should be included in the first-order network to serve as bases for gravity surveys at sea. However it was decided that this was unnecessary as port stations could be tied to existing first-order stations.

Dr. Graf said that certain modifications to the sea gravity meter were under consideration. These include a gyro mechanism and an accelerometer, which will give the product of horizontal acceleration with the angle between the instrument and the vertical. These will be fed to an analog computer, which will calculate corrections to the gravity meter readings and subtract them from the recordings of the instrument.

Thompson described the use of a La Coste gravity meter in an aeroplane. Radio-navigation techniques were necessary and an accuracy of about 10 mgal was obtained. (see Nettleton, La Coste, and Harrison, 1960; Thompson and La Coste, 1960).

See the section of this report on "Gravity" for further details, particularly of the La Coste meter.

Worzel said that observations at sea were (needed) most in the regions $1\frac{1}{2}^{\circ}$ outside the 1000-fathom line near continents, or the same distance from islands, platforms and trenches. Anomalies over the oceans were generally slightly negative. The most negative appeared to be in the zone from 10-40°, with a mean of about -15 mgal. He thought that this might imply an error in the standard formula for variation with latitude.

Resolution No.16 called for more gravity observations over island arc areas.

SATELLITE RESULTS

Cook discussed the theory of interpretation of observations of satellite orbits in terms of gravity variations. This can give accurate low-order spherical harmonics in latitude variation very accurately, but cannot give longitudinal variations at present. For this, orbits whose period is a multiple of the period of the earth's rotation are required. Results obtained so far are as follows :-

	Satellites (a)	Satellites (b)	Jeffreys' solution (free-air anomalies)
$10^6 J_2$	1083.0±0.2	1082.50±0.04	1093±5
$10^6 J_3$	-2.2±0.1	-2.23±0.26	+0.4±2.8
$10^6 J_4$	-1.3±0.2	-1.45±0.08	-2.2±2.1
$10^6 J_5$	--	+0.01±0.12	--
$10^6 J_6$	-0.1±1.5	--	--

The discrepancies from Jeffreys' solution are due to the small area of the earth's surface covered by gravity observations. This also explains the increased accuracy of the satellite determinations.

Spherical harmonic analyses combining the results of satellites and gravity measurements have been made by Cook, Arnold, and Kaula. Kaula described his method (Ref. 3a.xxix; also Kaula, 1959). The method is based on application of Markov analysis, i.e. anomalies in unobserved areas predicted using only the nearest observed anomalies, and on correlation of gravity anomalies with height or depth. The results presented at the meeting were carried a stage further than the references, and give results for geoid elevations to 8th order harmonics. The solution by auto-correlation analysis involved an 81 x 81 matrix of spherical harmonic co-efficients, with an additional 6 terms for the spherical harmonics determined by the satellite orbits. Standard deviations of harmonics up to 8th degree is ± 33m; for 9th and higher, S.D. is ± 9m.

Some features of the resulting geoid include high features of +36m in the East Indies, +33m near the northern part of the west coast of South America, and +30m in Northern Africa; and low features of -22m near the South Pole (giving the reported "pear" shape to the Earth), -61m in the Indian Ocean west of Ceylon, and -39m in the Atlantic, NE of the West Indies. There is a high gradient across the Marshall line in the Pacific, from +20m on the west to zero on the east. The North Pacific has an anomaly of about-17 mgal, and the South Pacific about -6 mgal. Over Australia, geoid elevation ranges from +10m in Western Australia to +25m on the north-eastern coast.

Cook suggested something might be gained by separate analysis of gravity and satellite data, and comparison of the results.

STANDARD GRAVITY FORMULA

Cook (Ref. 2b.xix) considers that the general form of the formula should remain unchanged. However, the constant and the $\sin^2\phi$ (main ellipticity) terms may need alteration. This should not be done yet, but should await the results of absolute determinations in progress, and better coverage of the oceans with gravity observations.

Various determinations of the reciprocal of the ellipticity are as follows :-

Krassovski,	1940	298.4
Jeffreys,	1948	296.85±0.66
Zhongolovitch,	1952	296.61±0.57
Heiskanen,	1957	297.2
King-Hele & Merson,	1959	298.20±.03 (from satellites)

He pointed out the advantages of using mean radius and gravity (instead of equatorial) in a new formula. He considers that small higher-order harmonics should not be included in the formula.

MISCELLANEOUS

Dr. Coron summarised a variety of symbols used by different writers, and suggested that a uniform code should be prescribed. Several people were strongly opposed to this and no volunteers could be obtained for a working group. I though that a resolution about this was rejected at the meeting; however, it appears as No.2 on the list of resolutions adopted.

Other resolutions passed concern standard time signals (No.4), orbits of future satellites (No.5), adopted value for Potsdam (No.6), support for a motion passed at Tokyo in 1958 concerning gravity surveys in the Far East (No.15), and recognition of the work done by the Isostatic Institute of Helsinki (No.17) and by Woollard's Group (No.18).

It was recommended that the Commission should meet triennially in the year before the I.U.G.G. General Assembly. National reports and reports of Study Groups presented at this meeting will be collated and presented at the ensuing General Assembly.

The following Special Study Groups were formed or continued :-

No.18 - Methods of absolute determination of gravity (Chairman, A.H. Cook).

No. 5 - International first-order network (C. Morelli).

No. 5bis- Technique of observations carried out on land by gravity meters (P. Herrinck).

No. 6 - Calibration bases - Europe (M. Kneissl); America (D.A. Rice); Central Asis (Y. Boulanger); Eastern Asia (T. Okuda).

No.20 - Gravity measurements at sea (J.L. Worzel).

No.17 - Results derived from artificial satellites (A.H. Cook).

No.21 - The use of gravity results in connection with studies of the interior of the Earth (J. Goguel).

3. GRAVITY

ABSOLUTE MEASUREMENTS

National Physical Laboratory, Teddington

(A.H. Cook, J.E. Jackson, Paterson)

I saw the swing with the Cambridge pendulums before departure for Australia. Recent improvements include a collapsible Helmholtz coil, a new method of timing by rotating a contact on a synchronous clock till pips in earphones disappear - WWV is used abroad; N.P.L. pips at home. A dummy pendulum is constructed of magnetic material. It is planned to observe Singapore-Darwin-Melbourne-Tokyo if possible, and repeat on return (Jackson, 1960). The trip was financed through Woollard. Observations were made in South America in 1958 (Jackson, 1959). The total weight is 360 lb. without vacuum pump or radio receiver.

Cook believes the request for deflection of the vertical at Woomera has petered out - he has not heard of it lately. As regards the Japanese pendulums, he considers the equipment too bulky and results Tokyo-Washington unsatisfactory.

Absolute gravity - Miss Richardson showed some drawings of the apparatus, which is not likely to be constructed for some time (Preston-Thomas, 1959, p.36).

U.S. Bureau of Standards (Dr. C. Page, Mr. Tate)

The apparatus for absolute measurements comprises a free-falling rod inside a falling case. (Preston-Thomas, 1959, p.45). Rod and case are approximately 1m long. The case runs on 2 vertical tubes at the sides, 4 wheels on one side, 2 on the other side (top and bottom). The rod has 3 razor blade edges for light cut-off, near 0, 25 cm and 1 m from bottom, i.e. about 0, 0.2 and 0.4 sec. after release. The case has 3 windows approximately opposite these. The case is of brass and the rod of pyrex, with painted silver strip for electrostatic effects. The rod has a hemisphere cemented on the bottom, which sits in a circular hole in the case. The case can be evacuated, normally about 1 micron, but he will try other pressures up to one atmosphere. He believes this shouldn't affect the results. The case is released by a simple spring catch, and given a small extra push by a spring-loaded device, which produces a separation of 1/8" to 1/4" from the rod. Owing to friction of the slides, the case slows up relative to the rod, and the gap closes near the bottom of fall. A piston on the bottom of the case falls into a cylinder with .004" clearance, with a rubber ring in a groove, which acts as a cushion. The cylinder can be connected by a hose to an adjustable volume with adjustable leak rate to give critically damped stopping and thus avoid jarring the rod. A light beam from behind the case and rod shines through these on to a slit in an optical system (100-mm microscope lens), and the slit is focussed onto a P.E. cell. The zero mark triggers two 1- or 10-Mc/s counters; the 25-cm mark stops one, and the 1-m mark stops the other. The triggers operate at a set voltage output of the P.E. cells, i.e. about 3/4 of full voltage (Fig.1). It is claimed that this has a constant relation to the position of the knife-edge irrespective of speed. The distance is measured by placing a standard scale (ordered but not yet delivered) beside the case, and setting the knife edges statically at triggering positions. He has tried tossing case and rod (successfully) after Cook's idea, by an air blast through the cylinder on to the piston. Experiment is to be carried out in a basement room, under 8 ft of earth, adjacent to Heyl's determination. The temperature is very constant here. No extra control is envisaged.

GENERAL

Geological Survey, U.K. (Bullerwell).

Gravity maps are prepared as overlaps on 4 miles to 1 in. for comparison with geological, aeromagnetic and other maps. They have used automatic computers for terrain corrections, 2nd derivatives, Baranov's "pseudo - gravimetric" anomalies etc.; also for putting principal facts on punched cards - this has been tried in field, without success.

Different density corrections are used for different geological formations, also anomalies are calculated for various densities, including 2.67 as a standard.

"Regional" spacing is about 2 stations per square mile. More detail is done if necessary.

Their gravimeters are 2 Wordens and 1 Frost. The Wordens change scale factor, about 1% in 2 years, fairly consistently. They do not use the large dial any more, except to determine when to return meter to makers. Temperature effect causing de-focussing has been observed. Calibrations are frequently made against a pendulum chain from Southampton to Aberdeen, about 700 mgal, particularly in setting out basic network.

An optical instrument has been developed for surveying terrain corrections on site. Masson-Smith has tried an integraph, but did not find this satisfactory. He thinks that the simple "Griffin" regional residual anomalies are as good as any, and generally uses a 4-km grid. They are mostly calculated by "hand" when plotted on grids.

Overseas Geological Institute, London (Masson-Smith)

Computer Pegasus (Ferranti) is used for terrain corrections, using a modification of Bott's method, and also for isostatic corrections. Results give isostatic corrections to Zone 10, and terrain corrections from 40 km to Zone 10. These are calculated for corners of 10-min squares. The size of the squares expands in doubling sizes outwards from the station. Terrain corrections inside a 40-km circle are done by chart - he has tried an integrator; this was not very successful, but might work if better made.

Mr. Masson-Smith has kindly sent me a draft of his paper on the method.

Shell Co. (Hague)

Gravity Analogue Optical Device. Profile is drawn for 2-dimensional features shaded in pencil to a standard degree of opacity. This is placed on a light screen; the light also passes through a graticule; this lets through a quantity of light proportional to contribution to anomaly, similarly to a dot-chart. Shading of the profile represents density contrast. Degrees of shading for various contrasts are determined experimentally and the operator must practice shading uniformly to required density. Graticules are made for various depth exaggerations. Calibration of equipment, paper, shading etc. is rather a long process and has to be done weekly. They now prefer to cut profiles in several thicknesses of paper rather than shading.

For 3-dimensional problems a special graticule is provided. For this, outlines must be cut or shaded for layers at various depths, and these must be done to different scales depending on depth.

A reading is taken by balancing the total light output against a standard, and reading a dial.

The machine is not working very well at present. The lights are normally left on continuously, as output changes considerably for some weeks after switching on; also lamps (fluorescent) last longer with continuous use.

Ottawa. Dominion Observatory (Innes, Hamilton)

Coverage of Canada is fairly good for a large part of the area. Many readings have been taken by float-planes landing on lakes (these may not be representative). Investigation centred on Hudson Bay has been made of the depression due to the ice-cap. The land rises SW but the Boubuer anomaly is flat. The isostatic anomaly (Hayford) rises also. They have produced a gravity map of Bouguer anomalies with a fair amount of detail. Positive anomalies occur only around coasts. A deep negative trough extends SW from the southern part of Hudson Bay; there is no geological explanation. Circular gravity negative anomalies occur in many places, and it is suspected that these may be associated with meteorite craters similar to those seen on the moon.

Instruments: Wordens, including 2 "Masters". Calibration tests showed one scale was non-linear, and could make an error of 0.2 mgal. (Usually Wordens are satisfactory on small dial). They do not use large dials any more for accurate work. They also have a North American. One North American and 1 Heiland have been converted for tidal work, with a P.E. cell in place of the telescope. Recording was done for IGY only - no staff was available to continue properly. See report on IGY programme (just out); also Innes (1958). Equipment under development includes a vibration gravity meter, for use in submarines (following Gilbert - the main advantage is that the natural period is far from that of waves etc.); and bronze pendulums, at present in Europe. These are used in high vacuum with temperature control (Thompson, 1959). All gravity meters are run over a calibration base (Ottawa-Washington) in spring and autuum, before and after the field season.

Calculations, including drifts, are done on punched cards after return of parties. Rough drift calculations are made in the field as a check. Base stations are put in first by accurate looping, and "detail" stations by running between 2 bases, or returning to the first. So drift is a direct interpolation. We can have their programme for IBM650 if we write and ask (see Schematics, Ref.3d.ii). At present they are working on a scheme for reducing base observations by machine. No isostatic corrections etc. are yet done on machines.

United States Coast and Geodetic Survey (Mr. Duerksen)

Two Worden meters are used. They are calibrated over a range of 200 mgal by repeat looping (leap frog) with tidal corrections (from Worden's tables, not Geoph. Expl. Suppt.) Ordinary surveys use one base repeat only. If this is within 0.3 mgal, the two base values are averaged and no drift distributed. If greater than 0.2, simple drift is distributed manually. Information is then punched on to cards with coordinates and elevation, and free-air and Bouguer anomalies are calculated. Elevations are obtained from benchmarks - barometers have been used occasionally but their accuracy is not good. Not much work has been done in mountains yet. Terrain corrections are not applied except for rough topography. Tidal corrections are not applied either. The accuracy aimed at is 0.1 mgal, for geodetic purposes only. He considers Worden large dials are accurate to about 1 mgal. Pendulums are now used only on calibration line. Calculations of deflections of vertical are compared with astro determinations. Accuracy is about 0.5 to 1.0 sec for radius about 500 km - relative deflections only. They rarely calculate isostatic anomalies now - this has been done for 1200 pendulum stations (before 1950 or so). Deflection-of-the-vertical work is done with free-air anomalies (Refs. 3a.iii, iv, v, vi, and vii) mostly by graticule, but a programme has been developed for IBM using 10-ft squares - only used where station density is not great. A circle is used for the central "square" (fig.2), and the effect of corners and edges is allowed for manually, also adjacent 8 squares; the remainder is done by IBM 650 with size of squares used increasing with distance.

United States Coast and Geodetic Survey (Rice)

He showed me Thompson's summary of gravity meters and their characteristics.

He thinks Worden large dials useful for work of accuracy ±0.5 to 1.0 mgal, and much easier than pendulums. Tests have been made on the calibration run.

He would be interested in a gravity tie from San Francisco to Melbourne by Panam or Qantas, possibly about March/June 1960.

Wisconsin University, Madison (Dr. Woollard, Rose, etc.)

The Gulf pendulum apparatus is being modified to attain an accuracy of 0.1 mgal, although this might be a bit optimistic. A reflected light beam is picked up on a .0001-inch slit by a phototransistor, and the signal is fed to a "Visicorder", with a paper speed of 50 in./sec. The record appears when the paper is exposed to light, and needs no treatment. Also recorded are time lines (.001 sec), WWV carrier and/or second ticks, and a chronometer, on separate traces. They are operating at very high vacuum - now about 50 microns, but may go higher. Corrections to previous results have to be made for the McLeod pressure gauge, which is outside the case of the pendulums and at room temperature. This probably affects Antarctic work the most, but may affect the Australian results. They swing 2 sets of pendulums, possibly at right angles. Three thermistors are located, two in the pendulum support blocks and one somewhere else, to ascertain that even temperatures have been attained.

They are drawing a Bouguer anomaly map of U.S.A. based largely on their own field work. Correlation of Bouguer anomalies with depths to M-layer by seismic methods where available is being studied. From this Woollard has produced a "Bouguer anomaly M-depth" map of U.S.A. (Woollard, 1959). This was compared with an Airy T = 40 km map of M-depth, and the differences between the two have been contoured. These line up with several major features in continental geology. He claims that Airy isostatic anomalies are equivalent to Hayford anomalies for approximately double the depth.

He claims that gravity anomalies must be partly explained by something in the mantle. To explain them by features above the M-layer, one must have a higher density of rocks under mountains, i.e. a smaller difference from the mantle. This may be due to a different distance from a low-velocity channel in the mantle, which has also low density.

Gravity data are filed and calculated on punched cards, for 4 or 5 different densities. They have established their own net of base stations and calibration line. Terrain corrections are not normally done, but probably will be done on IBM650 when required.

Haubrich is working on fitting power-series to areal gravity data at irregularly spaced points, so as to interpolate values at grid corners as required.

La Coste geodetic gravity meter has been found good, especially the big meter.

<u>Gulf Research and Development Pittsburgh</u> (S. Hammer)

The Gulf gravity meter consists of a spiral ribbon spring with a circular weight which rotates about a vertical axis. It can measure very small anomalies accurately and is also good on unstable ground, as it is insensitive to vertical vibration. Its period for these is less than 1 sec , and its rotational period is about 5 sec. It can be calibrated by a weight. It is thermostatically controlled. They mostly use Wordens now unless extreme accuracy is required. Gulf pendulums are quartz, approximately elliptical in horizontal section; the knife edges are pyrex.

Gravity is now used mostly for reconnaissance work - this and magnetic surveys localise features for seismic surveys and then drilling. Standard methods of interpretation, including 2nd-derivative and downward continuation, are used when data are good enough. Most gravity work is done by contract, and the calculation also. 2nd-derivatives are done by girls, because this is found to be cheaper. Much time is spent feeding data into IBM704 and in read-out, and relatively little in calculation. Downward continuation is done by IBM, as this is calculated for several depths. (An example is the separation of 5 blocks). For interpolation of terrain corrections in outer zones, see Ref.3b.vi. They have considered correlation of gravity and magnetic anomalies, but have no final answer yet. Latest development in interpretation is accurate density information available from gamma-gamma loggers. This is better than cores as a more representative density is obtained, but compares well with cores where both are available. Transmitter and receiver are about 10 in. apart along the hole, and the logger is held against the side by a bow-spring. If caving has occurred, contact may not be good and low density readings are obtained. Therefore a caliper run is made in the hole as well as the gamma-gamma. Variable densities occur in various areas, also variable velocity for seismic corrections. Law of propagation of errors - if W = f (x,y,z) & S.D's of x, y, z are e_x, e_y, e_z, then

$$e_W = \sqrt{\left(\frac{\partial W}{\partial x}\right)^2 e_x^2 + \left(\frac{\partial W}{\partial y}\right)^2 e_y^2 + \left(\frac{\partial W}{\partial z}\right)^2 e_z^2}$$

From this can be shown that lack of knowledge of densities and velocities is limiting factor in gravity and seismic interpretations respectively.

GEODETIC APPLICATIONS

U.S. Army Mapping Service, Washington (W. Kaula, Mrs. I. Fischer)

See technical publication (Ref. 3a.xxix) and Kaula (1959) for details of errors, methods, and use of machines in geoidal and deflection calculations. Also work on lunar occultations (± 150m), eclipses, and satellite data. He considers differences of deflection and shape of geoid within a country or continent should be determined by astro-geodetic surveying, and level and general tilt determined by reference to the world gravity net, rather than determining deflections etc. at individual points. He has plotted the error of representation in a square of side s with gravity station spacing d. Lately he is mostly interested in geodetic survey rather than gravity data. A Univac computer is used, also old Bendix (small types). No isostatic reductions are made. It is considered cheaper to increase density of stations to get better average free-air anomalies. La Coste geodetic portable meters are used with satisfactory results.

Ohio State University (Dr. H. Pincus)

Survey of Ohio (Ref. 3b.vii) - it is concluded that the major features of the gravity anomalies are variations within basement - depth of sediments is 3000 ft or so. Anomalies appear continuous with those in Canada where basement outcrops. No magnetic information is available. Faults with a throw of a few hundred feet, where there are layers of alternate densities could be missed by a gravity survey, as they would give only "noise level" anomalies.

Tidal gravity comprised mainly visual observations with a Worden - difficulties were in temperature and drift elimination. A recorder was made, but only 3 records were obtained.

They are interested in studies of gravity anomalies over basement, and correlation with geology, and shallow seismic work for engineering projects. He would like BMR publications on gravity and engineering.

Prof. Heiskanen, Dr. Uotila Isostatic anomalies are calculated for the Airy-Heiskanen method, T = 30 km only; apparently work is largely done in conjunction with the Isostatic Institute at Helsinki. Maps have been prepared for isostatic correction zones 13-11, Australian area (also now for whole world), for T = 20, 30, 40 60 km. (Copies will be sent to us). They will do isostatic calculations (30 km only) if data are sent - see paper by Heiskanen. We should calculate terrain corrections where necessary, and also mean elevation charts. They have about 8 doing isostatic corrections.

Geoid heights and deflections of vertical are calculated by machine methods. An IBM 650 is used; a 704 is on order. A manual circular method is used to a radius of 3°, 1° x 1° squares to 20°, and 5° x 5° squares beyond this. The error contribution using these radii is estimated as ± 0.1 sec. For geoid elevations, a manual method is used to 1.6°, 1° x 1° squares to 20° x 30° (at 45°) and 5° x 5° squares beyond. Charts are drawn showing corrections in squares rather than circular segments if manual method is used. Polar stereographic projection is used, and separate charts are calculated for each latitude (see Uotila's thesis, Ref. 3a.xvii). Free-air anomalies have been used so far, but isostatic anomalies will be used when enough information becomes available. In estimation of mean free-air anomalies, a strong correlation with elevation occurs; they should be corrected to the mean elevation of a square or area.

O'Keefe's paper (now published; O'Keefe, 1959) on significance of low order harmonics in the gravity field. These show isostatic unbalance in large areas of the world, which is not compatible with viscosity as in Vening Meinesz' theory. It must be maintained by extra strength or convection currents. Herriksen (in press) points out that previous determinations of hydrostatic flattening involve assumption that real and hydrostatic flattening are identical. Recalculations from (C-A)/C & J as obtained from satellite measure gives 1/500. The Vening Meinesz and Heiskanen formula for life of 2nd and 4th zonal harmonics gives 1000 yrs. (approximately). If these harmonics are due to a surface distribution of mass (which gives a minimum load on the interior), sea height changes would be of the order of 10m/100 yrs. Therefore the theory of viscosity as in Fennoscondia etc. is not applicable. This affects the use of Stokes' formula in empty areas, as this is based largely on assumption of equilibrium.

Columbia University (Dr. Worzel)

Progress on report on *Telemachus* cruise - a brief description has been published (Worzel, 1957). Several cross-sections have been drawn over the Tonga Trench. Most discussion is on one section near the north end, near Raitt, Fisher, and Mason's seismic profile. Talwani has calculated modifications to layers suggested by Raitt - these included 7.6 km/sec. layer under the trench (using densities from a graph of density versus velocity), and a rise in the M-layer to the west of the trench, similar to Puerto Rico (Talwani, Sutton, and Worzel, 1959).

M. Talwani is at present on a submarine survey in South Africa - he was working on *Telemachus* results, and may resume about December. They still want gravity information from N.Z. - can we get map for them.

Calculation of 2-dimensional anomalies of N-sided polygon (Ref.3d.i) is done by IBM704. A method has also been developed for 3-dimensions but has not been used yet (sea-mounts etc.) - (Talwani and Ewing, 1960).

He considers the Graf sea gravimeter much better than La Coste. Submarine observations are still necessary, for control of gravity meter observations and for use in areas where rough seas may make work difficult. Submarine observations may be by pendulums or by Graf meter (obviously with pendulums for control).

SEABORNE AND AIRBORNE GRAVITY MEASUREMENTS

U.S. Navy Hydrographic Office

This establishment does gravity surveys at sea using a La Coste marine type gravimeter (Ref.3c.i), originally in a submarine, but later models in surface vessels. They also have Worden, North American, old type La Coste (bulky) and Ray underwater gravity meters. La Coste geodetic meter (Fig.4) has thermostats, fits in an airline bag, and has virtually zero drift. The marine type hangs like a pendulum with wire rope supports through 2 cross frames. The top is driven in horizontal directions to annul the effect of horizontal movements relative to point of support. Two long-period horizontal pendulums act as accelerometers. An attached mirror reflects a light beam on to a P.E. cell, and drives a servo-mechanism so as to keep the pendulums horizontal; the movements of the servos are converted to corrections to gravity readings and recorded on digital dials; these are summed with the reading and recorded on a pen recorder. Vertical accelerations are considered to be averaged out by the integration mechanism. The dial setting of the gravimeter is normally left constant, and the recording increases while the beam is deflected down, and decreases while it is up; if too far off, the dial is adjusted to a new value. Thus the gravity is sum of the dial reading and the variation curve. Total cost is $150,000. They claim accuracy reasonably certain within ± 10 mgal. They have also 2 Graf sea gravimeters, but cannot get them to work.

They collect gravity data from all over the world. Some are classified because obtained for military purposes, and some because of oil companies etc. It can be obtained through the correct channels if required for defence purposes. They hope to publish information in form of 1^{o}-square averages before long. They have done surveys along radial lines to 300 miles, at intervals of 2 miles to 30 or 60 miles, for geodetic calculations at specific points - if large anomalies, closer spacing is used.

Calculations of deflections of the vertical have been done so far by hand, using Rice's methods, (Refs.3a.vi and vii), but it is planned to convert to machine calculations using Ohio State University methods (Orlin, 1959). They do not do isostatic corrections now - it is easier to obtain more field data and use free-air anomalies. Calculated accuracies by comparisons are ±.75 min on land, ± 2 min at sea - this may be due to steep gravity gradients near islands (e.g. change of -70 to +350 mgal in 20 miles or so).

All gravity data are filed on punched cards, or will be soon. Coding is by main areas, numbers of degree squares, and numbers of stations; also a reference is given to the base station, which is recorded separately.

University of California, Los Angeles, Geophysical Institute, (Dr. Schlichter, Dr. Harrison ex Cambridge).

Seaborne gravity - A La Coste gravimeter (Fig.4,Ref.3c.i) is used. This is similar to the one used by the Navy, but the top horizontal drive of the support is removed. The wire rope support is single only, and two telescopic shock absorbers are used at 45° to the vertical on each side of the square frame. This eliminates the need for horizontal drive. Accelerometers are horizontal pendulums with servo drives which constrain a box to remain parallel to each pendulum and also rotate a potentiometer whose output is converted. Gravity effect of beam motion recorded is not just deflection θ, but $a\ddot{\theta} + b\dot{\theta} + c\theta$, which gives the force on the beam. This is integrated to give an average, and thus if the beam is below the null position, the recording increases and vice versa. Comparisons have been made with (a) submarine pendulums, (b) shore stations, (c) simultaneous underwater gravimeter measurements. (Ref. 3c.i, also Harrison, 1959). The last test is the most reliable, and gives - 2mgal difference in mean (based on shore ties), with a standard error of + 2 mgal. The other tests give 3-10 mgal, but some stations are in high-gradient areas, also Eötvös corrections are uncertain. The meter has been used in an aircraft, and the results compared with surface data - the same general outline was obtained but detailed surface knowledge was not available from oil companies to enable a good comparison. (Nettleton, La Coste, and Harrison, 1960; Thompson and La Coste, 1960). In the aircraft, the integrating mechanism was not used. Because of the different time-constants it was found better to record directly and average visually. An attempt was made to repeat lines, but the pilot was asked not to correct course too violently, but rather to allow the plane to drift off course, so repeats generally are not identical. The meter has been used on a 500-ton tuna boat. It cannot operate in heavy swells, but it is estimated that it can be operated for 50% of the time.

Navigation is done either by aircraft, photos, or radio H.F.; they have considered using Shoran, Loran, or Doppler. There is nothing new in the ship itself. Harrison believes that work has been done on Doppler navigation at sea. This is classified, but not useful. He is also interested in inertial navigation (as used on the Nautilus) for ships and aircraft, but this is classified also. The instrument continuously integrates accelerations. A paper on the theory of sea gravity observations is to be published in "Techniques & Methods in Geophysics". This will discuss a cross-modulation effect, between horizontal and vertical accelerations. He believes this effect is present in the Graf sea gravity meter and could give errors of 5-500 mgal.

Results and interpretation

It is no use calculating isostatic anomalies where it is obvious that large anomalies will remain under any system - it is better to consider all variables, including densities, and try to fit the observed data. Sea-mount basalt gives best fit for a density of 2.3 (see paper). Positive free-air anomalies of about 40 mgal have been found over the edge of the continental shelf west of California due to extended effects of compensating layers; negative anomalies occur just beyond this. Correlation with topography has been found in California Gulf - some peaks are buried partly or completely, some on one side only, some not at all - the latter are in the middle. The Mendocino scarp cuts E-W across the continental shelf and parallel features. Analysis shows that part of the anomaly or compensation must come from below the M-layer. Seismic work has been done in the same area. Analysis of anomalies near continental edges should give depth, position, and density of compensation. They have not done topographic corrections yet for most sea-work - some isostatic anomalies have been calculated.

Scripps - Prof. Menaud at Pasadena (California Institute of Technology)

They are planning an oceanographic trip around the world westwards from California, from N.Z. south of Australia to the Indian Ocean, then through East Indies to the Pacific. The programme will include seismic and gravity observations using the La Coste meter. Probably they will call at Melbourne and Fremantle. He has arranged seismic shooting in conjunction with an Australian authority in W.A. He expects to be in Australia next autumn, and they could arrange a joint programme with Worzel. They have a big programme in the Indian Ocean. The La Coste gravimeter is operated in conjunction with U.C.L.A.

4. TIDAL GRAVITY

Liverpool Tidal Institute, Bidston Observatory, Birkenhead (Dr. Doodson, Mr. Lennon).

Instruments Two Milne-Shaw seismographs are used with modifications (Ref. 4.v.). The mirror pivots are sapphire gramophone needles. A slow drive has been fitted, giving one week per record (Lennon suggests 3 days would be better) with no side movement. Meccano gears are used for this. Time marks are made each hour by removing the cylindrical lens, and a darker line at midnight. All lights are dimmed. The damping ratio is about 1.4 to 1.5. The period is measured weekly and is about 17 sec giving a sensitivity of 10cm/sec. He believes the period could be as high as 25 sec. The sensitivity is proportional to T^2. Calibration is done with the working period and shorter periods. Because of defects of the screw threads, one must throw the light spot well off scale at either end, and move by steps of only 0.2 sec within range, and work in both directions. Differences are obtained between values 1 sec apart. Drift is about 1 - 5 sec per year. It is important to locate the instrument at the centre of the pier. Old piers (50 years) are very stable, particularly the earthenware pipe type (about 2-ft diameter). Effects of humidity may be important. They have continuous records now for 4 years. Earthquake motions are too rapid to be recorded.

Zollner pendulums (Fig. 3) are no better as they have a high drift and no greater sensitivity and are difficult to calibrate. They are being manufactured by Askania, and may be on sale soon. They give different answers from the Milne-Shaw.

Bidston station is close to 30-ft marine tides, and loading and attraction affects the horizontal component. (Refs. 4.iii and iv). These effects are several times the direct effect. Effects of attraction are calculated by "terrain correction" method. Loading is difficult to separate. Amplitudes are inferred for some tidal components, and the residual is taken as a loading effect. All tilts line up in NW-SE direction, whatever the cause; this is the effect of the Caledonian block.

Analysis. Three methods are available - Lecolazet, Pertzev and Liverpool Tidal Institute (Refs. 4i and vi). The latter charges £1-10-0 for record reading, £2 for drift elimination and £3-10-0 for analysis for 1 month's record. One year's continuous recording is preferred wherever possible. The recent international symposium recommends analysis by all 3 methods!! The work is done by desk computers (2 girl-days per month). Effects of attraction are appreciable up to 1000 miles.

Variations. He considers that one year's recording at each site would be necessary to study local effects. He can see no advantage in simultaneous recording at two sites.

Royal Meteorological Institute, Uccle (Dr. P. Melchior)

His main reason for interest in earth-tides is the effect on astronomical measurements. He believes interesting results can accrue from measurements over local geological variations, but as the whole systematic recording of earth-tides is new he does not know what can be got out of this.

Equipment comprises an Askania recording gravity meter, with speed about 1 cm per hour, sensitivity .03 mgal/cm, full range 6-7 cm (Ref.4.x). This had a high drift for the first 6-7 months, then settled down. After an interruption (2-3 months), the high drift started again. The instrument is in a vault enclosed by a corridor, with a dehumidifier in the corridor. The regular temperature of the gravity meter is about 40°C. This is controlled by inner and outer heaters and thermostats. A change of room temperature from 26.5° to 25.5° changed the drift rate from 3 mgal (? or more) per month to a slightly negative drift. He is very pleased with the general operation. Recording is done with a galvanometer and spot follower. One record is obtained per month, at a speed of about 1 ft per day. There is very little effect from the sea, and none from traffic. The meter was calibrated before setting up, and has not been checked since, but will be after say 2 years. The calibration of the recorder is checked weekly against the reading-dial setting. He plans to use 3 gravity meters soon and make intercomparisons by simultaneous recording at the same place, and also with international gravity meters - this may show up systematic defects.

Horizontal pendulums were manufactured in Uccle workshops, and have a fused quartz system. The main frame is a tetrahedron of quartz tubes, about 1/4 in. diameter and 8 in. high; fine fibres are fused to the frame and beam, similar to the Zollner system (Fig.3). He believes it is necessary to record at 200 ft below the surface and is installing them in a mine shaft. He is also making sets for Italy etc. The pendulums are enclosed in a Perspex cover. Three levelling screws are used at right angles, and the central one is not touched after initial adjustment. One is used for adjusting sensitivity and one with a micrometer for calibration. Later models will have a metal plate of prescribed thickness to place under the footscrew for this. The pendulums are operated at a period of 80 to 100 sec , but he believes about 200 sec could be attained. The mounting consists of 3 holes drilled in rock, with metal plugs about 4 in. long and 1 1/4 in. diameter, let into the holes with bonding material (see reference above), which is a plastic with accelerator. The instrument feet are in an oil bath to avoid corrosion effects etc.

Programme. He believes any station in Australia will be of great value as there are only a few observations in the southern hemisphere at present. A station in the center of the continent would be of interest, as the effect of sea-tides would be a minimum. Also stations on Pacific Island would be of interest. In New Guinea, because of volcanoes and earthquakes, a station may not be of much use for values of tidal constants, but may be of interest in connection with eruptions. The main work is in setting up new stations - once recording has started, the work is a minimum. The minimum period for recording should be 6 months; 12 months is better, and at least one permanent station is desirable. He believes that simultaneous recording at different stations would be advantageous.

Methods of reduction by three different formulae are done on IBM650 (Refs. 4.viii and ix).

Institute de Physique du Globe, Paris. (Mme Queille - Lefevre) (Ref. 4.xi).

An Askania gravity meter (old type) is enclosed in a box evacuated to 30mm of mercury to eliminate pressure variations and for thermal insulation. Remote control by servo-motors is used. The gravity meter is inside 2 copper sheaths. The outer one has heater and thermostat (resistance) windings. This is used instead of the normal heaters, and is controlled to .003°C. The heater is never right off, there is always some current; this is supposed to eliminate an effect due to the thermostat switching on and off.

Dominion Observatory, Ottawa (Innes, 1958)
and Columbus, Ohio (see notes in gravity section)

University of California, Los Angeles (J. C. Harrison)

La Coste geodetic meter (Fig.4) is used with a null servo-drive system, a zero-length spring, and a lever on the spring support. (Woollard, 1956; Clarkson and La Coste, 1956 and 1957; La Coste, 1957). An optical chopper photo-electric mechanism is used to drive the servo; this gives an A.C. signal with a phase component to determine the direction. The recording is on paper about 1 ft wide, and the full width represents 0.4 mgal. Accuracy is about 1 microgal; he believes it could be better. He plans digital recording at 0.1 microgal every minute or so. The system is pressure sealed and double thermostat control is used. A barometer on the outside checks the internal pressure. I.G.Y. programme included about 12 stations around the northern hemisphere, including one on the equator in Central Africa, at an equinox with the moon on the equator. This recorded the maximum possible tidal effect and the record is nearly a pure sine-wave. He believes there is a phase delay of about 2 minutes between the recorded and theoretical curves, but is not sure whether this may be due to instrumental time constants in servo-mechanism etc. Inland stations give good accuracy and theoretical amplitude factor, but at coast stations this is not good because of sea-tide interference. He hopes to study fortnightly and perhaps yearly tides - a phase-lag would indicate transition between elastic and plastic behaviour of the mantle etc. Power spectrum analysis has been made of tidal records. This is somewhat similar to gravity residual effects using weighted means of surrounding points. This brings up "lines" of frequency in the same way as an optical diffraction grating. The advantages over Fourier analysis for non-multiple frequencies are that it eliminates drift as low-frequency noise, and steps appear as high-frequency noise. Disadvantages are that side-bands occur as with optical interference, and there is some difficulty in separating lunar and solar tides.

Pendulum. He plans direct measurement of the movement of a 7-ft rigid pendulum, supported from flexible bands to eliminate rotation or oscillations. The stem consists of a 1-in. brass rod, and a cylindrical bob about 3/4-in. diameter and 5 in. high. The movement is measured photo-electrically by a chopper, similarly to the gravity meter, operating in 2 directions, of a focussed beam on the bottom of the bob. Calibration is done by a micrometer screw on the stem above the bob, or alternatively by a ball dropped and picked up by an electro-magnet. The system is enclosed in an aluminium screen with the chopper drive outside, to prevent convection due to heat from the motor or other sources. The trial model had 5-minute oscillations, whose cause is unknown. He believes 1 month of good recording with a gravity meter is adequate for daily and shorter-period tides, but longer recording is necessary for pendulums etc. No calculated corrections have yet been made for ocean tides.

5. GEOMAGNETISM

MAGNETIC OBSERVATORIES

Meteorological Institute, Air Ministry, London

This Institute operates the magnetic observatories at Eskdalemuir (southern Scotland) and Lerwick (Shetland Islands) and has a computation centre at Edinburgh. The seismological observatory at Kew also comes under the Institute.

On my first visit I met Dr. Stagg (about Assistant Director level) who showed considerable interest in the Australian geomagnetic observatory programme. Jacobs, Frith, and Houghton, who are also interested in geomagnetism, were absent. Arrangements were made for me to visit Eskdalemuir and Edinburgh.

I met Mr. Jacobs on a later visit. He is interested in the publication of back geomagnetic data - theirs should be up to date by 1962, thanks to a special grant for the two Vari-typers. He was also interested in the definition of rapid-variations adopted at Utrecht. He believes all magnetograms should be published, but the British Government won't approve the expenditure for this, especially in view of expense of programme of publication of arrears of data. He is also interested in atmospheric electric measurements (see under Eskdalemuir). Automatic digital recording on to magnetic tape is being developed for solar recorders.

Royal Observatory, Herstmonceux, Surrey (Mr. Finch)

The observatory is operated by the Naval Ministry and is responsible for the Hartland (Devon) Magnetic Observatory which was recently transferred from Abinger. As with the Meteorological Institute, geomagnetism is irrelevant to the main purposes of the organisation, and it is therefore difficult to obtain finance for projects or improvements.

Hartland has the Schuster-Smith coil for H and the Dye vertical for Z. These are wound on marble formers, whose dimensions are checked by the National Physical Laboratory at Teddington every few years. Although they make comparisons occasionally with international standards, such as Rude Skov and Fredericksburg, they do nothing to adjust their standards to agree with anything else. Finch seemed to be unaware of the term "International Magnetic Standard". He regards their magnetometer as instruments for measuring the magnetic field and as such believes that they give the correct values. Any discrepancies with other measurements need explanation, but he doesn't appear to be concerned that the British standards might be wrong.

He has proposed to purchase a proton precession magnetometer similar to those ordered by the Meteorological Institute, but as the coil magnetometers are satisfactory, it was decided that this was unnecessary.

He has been asked to investigate seismic and micro-seismic disturbances at Herstmonceux in connection with the foundations for telescope.

Publication of magnetic hourly values is several years in arrears, but the backlog is being reduced. It is intended to publish copies of all magnetograms for recent years. Preliminary scaling of records is done at Hartland, and the records are sent to Herstmonceux for filing. Adoption of baselines and final conversion is done at Herstmonceux.

World magnetic charts are prepared at Herstmonceux and issued by the Admiralty. In this connection, they are interested in secular variation.

Finch had noticed a difference in the records at Abinger and Hartland - at the latter the Z-component of variations is much larger. This is believed to be due to proximity to the sea. He was unaware of Dr. Parkinson's paper on this subject but was interested to learn of it.

<u>Meteorological Institute, Eskdalemuir</u> (Mr. Day)

Magnetographs include a La Cour normal and rapid, and an Adie insensitive converted from a previous model. Absolute instruments are a Schulze inductor, which is overhauled annually; a BMZ which jumps and seems to be a bad model; a QHM with a scatter of 10 gamma or so, due to a bad circle; a Schuster Smith coil wound on a marble former, whose dimensions were measured at NPL, and are checked every few years. A standard current is supplied by potentiometer and a standard resistance. The coil is set at an angle of 1° - 5° either side of the magnetic meridian, and the field is annulled at the centre; the angle is read directly from a spot on the scale. Under disturbed conditions the field may be outside the range of the instrument, and measurements are postponed. A proton magnetometer is on order - see Mr. Colingbourne at Kew.

Other instruments include solar radiation, potential gradients, and meteorological instruments.

The magnetographs are in a large double vault with 3-ft air space between the walls and ceilings. Very constant temperatures are obtained, the annual variation being ±2°F.

Records are scaled at the observatory and converted at Edinburgh. Records are fairly quiet.

Two Antarctic trainees spend about 3 months at the observatory on magnetism and meteorology. They are trained in seismology at Kew.

There is a Senior Scientific Officer in charge and an Experimental Officer as Deputy Superintendent (Edmonson). Residential quarters are provided in the observatory grounds.

Geomagnetism is incidental to meteorology, and no research is done.

Edinburgh (Mr. Cranna). Hand methods of computation are used, such as slide rules, logs, and multiplication tables. They have a Bruns-viga hand machine, and adding machines. (Mr. D. Gill expressed interest in a job in Australia).

The results are published in observatory year books - 1938 is the standard reference, and 1944 the most recent; others are on the way as there is a big programme to publish back results. Mean hourly values, sums, means, extremes and ranges and harmonic coefficients up to order three are published. I obtained a copy of the form used for harmonic analysis. For Eskdalemuir, north and west components, as well as H & D, are published

A Vari-typer with several sets of symbols is used for setting out the tables.

Kew Observatory (Mr. Colingbourne)

A quote has been obtained from Venner's Electronics, of New Maldon, Surrey, for a proton magnetometer. This comprises a transistorised counting unit, to operate from a 12-V D.C. supply or mains; a sample detector head, a pre-amplifier (to be located within 12 ft to 20 ft of the detector), coaxial cable and four leads, with maximum resistance for one lead of one ohm, and for the other three of five ohms, to connect to the counting unit. The display is on meters and is digitised; this gives the time taken for 2048 cycles, counting pulses of 100 kc/s, with an accuracy of 1 : 10^5. The instrument ordered can measure any field from 0.42 to 0.52 gauss, using nine switched ranges. Price is £480 sterling.

Another quote was obtained from Elliott's, somewhat higher. This model could be adapted for recording.

Meteorological Institute, de Bilt. Proton Magnetometer. The coil pre-amplifier and tuned amplifier are made in their own workshops, while the crystal oscillator (10^5 c/s), counters, and main amplifier are purchased.

Amplification factor is 10^6, at frequencies of 2000 c/s $\pm$ 50. A field of 200 oersted is switched on for some seconds, and then off, and then decays for 3 sec. After 100 cycles, a gate is opened and the 100 kc/s pulses are counted for 900 signal cycles. Accuracy is about $\pm$ 1 gamma. The coil makes a tuned circuit with the other components at 2000 cycles. Ordinary water is used in a perspex container/former. Counter dials, clock etc. can be photographed. The instrument is intended for use with absolutes at Witteveen.

Meteorological Institute, Dourbes - magnetic (Ref.8.v). M. de Vuyse, also Dhaenes.

Absolute measurements are made with a new torsion magnetometer of Askania. The same head is used for all 3 components. Cost is about £2000. Dourbes has the first model, 9 or 10 more are under construction. He believes this is very satisfactory and quick and can be used to obtain pier differences etc. readily.

Also a GHZ, GDH etc. are used (see book). These are not calibrated by measurement as with the Schuster Smith coil, but by determining the coil constant at a place where H is known (e.g. through QHM) and using a standard current. When this is determined, Z or D is determined using the same coil constant and measuring the current accurately.

Askania inductor gave some troubles at first, but after "running in" for 48 hours (by motor drive) good results have been obtained. A special scale with a long light beam has been made for reading the galvanometer.

A set of La Cour variometers with visual reading is kept in the absolute hut, and readings are taken when absolute observations are made. There is also provision for instantaneous time marks.

Rapid variometers are used and also loops. Z and F were installed first (F because the slope of the ground is right). Now H is being added.

Scaling of records is done at the observatory, and the sheets are sent to Brussels for punching on to cards and treatment on IBM 650.

Institut de Physique du Globe, Paris.

(M. Selzer, Leschault (?), Schlich; Thellier is Director of Geophysics Institute in general, including seismology and gravity).

Chambon - La Forêt magnetic observatory is located about 70 miles SW of Paris. M. Blum is O.I.C. and Mme Blum is editress of Annales de Géophysique. M. Selzer, M. Stefan and Mlle (Roquette?) were also visiting for the day. A second observer and a technician are included in the staff.

A Rubidium vapour magnetometer is at experimental operating stage. Dr. Monier is working on this, but was absent on leave.

Potential gradient and conductivity measurements were discontinued 10 years ago.

Absolute magnetic instruments include a Cambridge inductor. This is not very satisfactory, but has a rather good arrangement of adjustments and light spot from galvanometer.

A theodolite-declinometer was redesigned by a French company to meet special requests by Selzer and others. The telescope is mounted to one side and a magnet in the middle can be mounted simultaneously. An eyepiece is used for reading the magnet. A silver block is used for damping; this has a slight magnetic effect if too close. A QHM can be mounted instead of a magnet.

Three separate huts are used, one for each type of instrument. The inductor hut is partly over the magnetic vault.

Variometers - 3 visual old-type variometers are mounted in a vault and read regularly 3 times every day; they are also used to detect disturbance. Three old variometers record at low sensitivity. There are also 3 La Cour normal-run variometers, and a La Cour quick-run recorder with 3 variometers constructed by Selzer; these have more sensitivity and are damped. The effect of electric trains 30 km distant shows on records, but it is claimed these can be distinguished by their sudden beginning and end, and the fact that main effect is in Z, whereas natural changes are strongest in D & H.

(Dichopoulos?). This consists of about 60 m length of mu-metal laminated ribbon, with several cross-strips at ends and gaps in the middle at the sensing head of a magnetic tape recorder. Slow moving tape is used. The array is aligned in the magnetic meridian, so that the normal field in the gap is zero. Variations in D are then magnified and recorded. The tape is played back so that the variations are heard as audio frequencies.

Bar-fluxmeters. Three components are housed in an old farm shed, with very primitive mounting. Also 2-component earth currents are recorded giving 5 traces on one Kipp and Zonen camera. A direct record of one component can be made on a spot-follower if required.

pc occur chiefly in daytime and pt at night, accompanying b or bp' elsewhere.

(Overhauser ? Ed.)

A Proton magnetometer is based on the (Hausoffer?) effect. If a small quantity of a certain organic liquid is dissolved in water, electrons are released which have the effect of partly orienting some protons in the water when excited by V.H.F. Thus a large magnetic field is not necessary and in principle the protons are continually precessing, so that continuous measurements are possible. However, frequency measurement by counting limits readings to 1 every 10 sec , if an accuracy of 1 gamma is required. Liquid must be kept in a refrigerator as it becomes destroyed at normal temperatures after 20 min .

Magnetron. Mu-metal rods in a basket arrangement (Fig.5) have the effect of concentrating the earth's field to a sufficient value to put the magnetron on the most sensitive part of its characteristic, and also of magnifying variations considerably. This is not fully developed. Records are scaled at the observatory and baselines are adopted by Selzer and computations carried out at Paris.

Records from Chambon-La-Forêt, (Bangui), Tananarive, Kerguelen, Dumont Durville, Charcot, are all dealt with and retained in Paris.

Nuclear explosion effect - see Journal of Geophysical Research, (Christofilos, 1959). Three cases are reported and apparently the best is 22hr 12 min , 6/9/58. A.K. Harris had visited Selzer on 8/9/59, but could not give exact times of explosions or U.S. recordings. The effect was recorded not only at the conjugate point (which was predicted) but apparently all over the world. French times of recording, including those in the Antarctic area, agreed within a second or two. The effect was recorded on bar-fluxmeters.

Dominion Observatory, Ottawa (Madill, Serson, Neblitt)

The permanent observatories (about 8 or 10) include several in or near the auroral zone; about 10-12 temporary ones are used in addition. The permanent ones have Ruska variographs, and the temporary ones fluxgates (Ref.5.v) - their standard is not so high. One Askania portable has been used at Victoria, but was not satisfactory. QHM's are used for H. Some observatories have Ruska dip-inductors which give good results. One has a Schuster-Smith coil. They have only one BMZ, but this is not working.

All scaling and conversion is done at the stations. Q-indices have been started at head office - 10 months have been done for Yellowknife. There is still much IGY data to be treated.

They have found a suggestion of an inner auroral zone.

Instruments (Serson)

The field instrument is a fluxgate coil attached to a Cooke Troughton & Sims theodolite. D & I can be measured to the accuracy of the theodolite (0.2'); F to ± 5 gammas by a current in the coil. An observation of three components can be made in about 15 min. Difficulty has been found in checking standard current in Arctic regions.

Observatory type fluxgate (Ref.5.v) is used as a visual indicator. The limit of sensitivity is about 3 gammas owing to noise level. Flat response ranges from periods about 1/2 sec to infinity; a peak occurs at about 0.1 sec. A Hartmann & Braun recorder is used, giving a point every 10 sec, alternately on D, H and Z, in 3 colours. Erratic drifts occur, but no steady drift over periods of a year or so.

Proton Magnetometer. This is operating but has not been finalised. An anchor ring shape is used to eliminate pick-up of external noise. A Mc/s counter gives time in sec, and this has to be converted to gammas. Cost is less than $1000. A 4-coil system is used to give a very uniform field at the centre (Fig.7). The inner coils have 50 turns, and the outer coils 113 turns. Separation of the outer coils is about 5 times that of inner coils; diameters are the same (wound same way). It is claimed that the advantage over a Helmholtz coil is about 100 : 1. A 3-component technique is achieved by reversing the current in the coils (Ref.5.vi). The same coil is used for energising and detecting.

U.S. Coast and Geodetic Survey - Fredericksburg Observatory (Mr. Gebhart, Mr. Gravens).

Absolute instruments - The Sine galvanometer consists of a coil on a marble former, the constants being determined by measurement. A standard current is passed through the coil, from standard cells and a standard resistance of 10 ohms, to give a predetermined current; the same current is always used. The coil and telescope are rotated until the magnet mirror is again perpendicular to the telescope. The angle of rotation is nearly 90°.

Johnston Universal Magnetometer for H & Z, consists of a Helmholtz coil on a pyrex former, which can be set either horizontally or vertically. The inner coil is rotated to indicate null field. This has been constructed over many years, but has not been put into use yet.

Japan G.S.I. magnetometer - observatory model. This consists of a Helmholtz coil on a theodolite base with a telescope at the side. A small rotating coil enclosed in a metal sphere is used as a null detector. The axis of this coil is set to give directions D & I, then the Helmholtz coil is used to annul the field. Standard cells and resistors are used to give a standard current and hence to measure F. A field model is also available, with somewhat less accuracy. The observatory model is priced at $5500. Indication is by an amplifier and magic eye. Two men are required to operate the instrument.

A Ruska standard magnetometer and inductor are in use.

A Proton magnetometer has been constructed with coils for backing off H & Z so as to give a measurement of the other component (Ref. 5.vii). If the unwanted component is backed off to within 500 gammas, this gives 1-gamma accuracy in the desired component. For H, the frequency is 800 c/s, and the instrument counts 500 cycles. For Z and F the frequency is 2400 c/s, and 2000 cycles are counted. H accuracy is ± 1-1/2 to 2 gammas, and is not as good as the sine galvanometer. A toroid type has been tried, but electromagnetic noise level is low and a cylinder appears to work better. H accuracy is low because of the small amplitude of the signal (about three times the noise level) as well as the low frequency.

Variographs are of the standard Ruska type, with magnetic temperature compensation. Also magnetic compensation is used on the D variometer to allow for the effect of the H & Z magnets. This introduces a D temperature coefficient, but a very small one. Time marks are made only at intervals of one hour; triple-faced mirrors are used for reserve traces. The Z magnet is similar to that in a field balance, with sapphire knife edges and quartz bearers.

The Storm Ruska magnetograph is similar but with coarser fibres for D & H, and the Z magnet weight is adjusted to give about 1/5 sensitivity. An inclined mirror is used in only one set.

The rapid-run Ruska magnetograph is similar in principle to the La Cour, but a separate sheet of paper is used for each component, with a 20 mm-channel. There are about 50 mirrors for each component, arranged in the arc of an ellipse, with the lamp and the main mirror at foci so that the total light path is invariable (Fig.6). The sensitivity is about 1 1/2 - 2 gammas/mm. Synchronour motor drive and translation is used. Time marks are made each 5 min and at 59 and 01. Recording speed is 4 mm/min. Two hours elapse for each drum revolution.

A visual recorder, home made, H only, is used for warnings.

A fluxgate magnetograph has been converted from a submarine detector and is used for studying rapid variations, say 50 c/s to 0.3 c/s. Full range can be 1 gamma. This is experimental at present.

Special rooms are available, one with temperature control, and another two adjacent rooms with individual temperature control; bases for gravity observations are also located at the observatory. One room has Fanselau coils for simulating any field to ± 12,000 gammas, or annulling the earth's field. These consist of 4 coils in each of H & Z directions, and 2 coils with a small number of turns in D in a true Helmholtz arrangement. With 4 coils, 2 larger coils (about 6 m diam.) are closer than for a normal Helmholtz coil, and 2 smaller coils (say about 5 m diam.) are located at a greater distance; an equal number of turns is used on all 4. The coils are connected in series. The resultant field has a variation less than 1 gamma over a cubic meter at the centre. Auxiliary coils with a few turns only, are wound over the main coils for use with a differential magnetometer to maintain constant field in time.

Cosmic Rays are recorded in a sphere surrounded by lead-shot; electrometer and amplifier is used for recording; the electrometer is grounded every hour.

The observatory has elaborate wood-working and metal workshops.

Residences are provided for married staff only. Some live in the town, which is 10 miles distant.

Washington Office (Mr. Svendsen, processing of data from observatories).

Hourly values are scaled and checked at observatories, also baseline observations and scale-value measurements are scaled and calculated. They are plotted up at Washington and values are adopted, generally about 6 months later. Hourly scalings and base line and scale-value data are punched into cards. This takes about 3 days per observatory-year. The results are punched into new cards, 6 hours of one component per card. Code cards (Q, U, and S) are merged and gang-punched into the hourly cards. Sums and means are taken accordingly. A check is made of card-punching by summing individual hourly values and subtracting from the manual sum. Note that values are tabulated in local standard time - this leads to a complication in the code cards, which are for Greenwich days. Computation is done on IBM 650, 2-2½ hours per observatory year. The Cheltenham-Fredericksburg standard is adopted for all reductions. There is need for comparisons with other U.S. observatories. They haven't done much to sort out international ties. They generally adopt each observatory's local standard and publish data re inter-comparisons. The proton magnetometer suggests that the standards are out by a few gammas.

MAGNETIC SURVEY TECHNIQUES

U.S. Coast & Geodetic Survey, Magnetic Charts - Askania portables have been used successfully for field observation corrections. These are considered good to 200 miles radius; in some placed 500 miles. There are 100 repeat stations and 5000 original stations in U.S.A. They run the variograph for 2 weeks or so, with one man full-time, doing absolute observations and scalings. They don't attempt to compensate Z for temperature. High drift is found in Z baselines. Charts are prepared for U.S.A., and for the world, using about 100,000 observations.

Surveys are done for compass-swinging sites at aerodromes.

Magnetograms are published, 4 per page. A gap occurs in publications from 1931-49. Policy is to close this up as time permits.

For method of preparing charts (see Refs.5.i and ii). The "impulse" method is based on the hypothesis of simultaneous occurrence of patterns $\partial^2 F/\partial t^2$ at certain epochs all over the world. No reduction has been made of airborne observations to ground level.

Cambridge University (Sir Edward Bullard, Dr. Maurice Hill, Tom Allen)

A "fish" proton magnetometer is towed behind a boat, a coaxial cable connects the detector to a pre-amplifier, a few yards away. This is connected by a cable to the boat. The signal is recorded on perforated tape in digital form, and also on paper by a chopper recorder. Also navigation information (position and depth) is fed on to the tape. The tape is scanned for 1st and 2nd differences to eliminate odd readings. Two heads at right angles are used to measure the field near the equator.

Results. A large anomaly was found off Lisbon - 8° or so in declination. Various anomalies are common in the deep ocean. A large one occurs off Brittany, but French geophysicists say that this is not present on land.

London Imperial College, Kensington

Bruckshaw was absent and I saw Dr. Hall (ex N.Z. gravity). He is interested in a rocket magnetometer project, and wants to measure the field at the surface and compare this with the field at heights. He is particularly interested in diurnal variation in F at various heights - the rocket proton magnetometer measures F only. However fluxgates in the rocket also measure approximately 3 components of total field in flight relative to the axis of the rocket - this includes the natural field and the field due to the rocket. This is used for corrections for heading errors on the proton magnetometer. He would like absolute measurements at the testing station or a ground station. I advised him to write to the Chief Geophysicist. He expected to visit Melbourne in January 1960 from Woomera.

Ottawa, Dominion Observatory. Airborne 3-component magnetometer (Ref.5.viii) operates on a stabilising platform controlled by gyros, which keeps the vertical fluxgate detector vertical ± 3'. The horizontal ones turn with the aircraft, and outputs are combined to give H and the angle between the aircraft heading and the magnetic meridian. Also the heading is recorded with respect to the gyro. Accelerometers are used to give automatic corrections to the gyro action; also wind speed is differentiated to obtain fore and aft accelerations. Dials give direct readings in gammas. The readings can be integrated for 5-min periods, and the observer writes down the answer every 5 min. At the same time, a pen recorder writes the last 2 figures continuously - if this goes off scale, a new record comes in at the other side of the paper.

Lamont Geological Observatory, Columbia University, N.Y.

A "fish" fluxgate metnetometer, on the same principle as Vacquier's original airborne model, is used with Vema.

Interpretation of anomalies in the Red Sea - apparently a series of dykes running parallel to the shore. Also a gravity "high" has been found, indicating igneous basement. Readings are not close enough to enable resolution of individual dykes. Type anomalies have been calculated for n-sided polygons with one infinite horizontal dimension, by IBM 704; the programme was adapted from the gravity programme.

U.S. Navy Hydrographic Office. Airborne magnetometer.

A project is in hand to fly all oceans of the world. A survey is in progress from Christchurch-Melbourne-Hobart-Perth-(Timor?)-Darwin- ENE at present (Oct.1959). Results will be available to Australian Government in return for use of airfields. They intend to apply for a clearance to fly over the Australian continent on the same basis.

Instruments include a fluxgate 3-component magnetometer, which measures F, D,& I. The magnetometer is mounted in a pendulum with a baffle hanging in an oil pot, to maintain constant position in relation to the vertical and the heading of the plane. Accuracy is for F ± 25 gammas, D ± 15' (3' under ideal conditions), I ± 3'. Heading is checked (a) by optical observations of azimuth, (b) by a photo-electric periscope for azimuth, using the sun or stars, and (c) by a gyro-compass with slow drift. The difference between magnetic heading and true heading gives D - this is integrated over 100-sec. periods to smooth fluctuations, then the recorder is re-centred to zero. F is measured by backing off the field in a coil with standard cells. Corrections can be made accurately for temperature and ageing, but vibration affects the cells severely. Each element has a servo-drive to orient and adjust the current, a synchro-mechanism for setting in discrete steps (backing off) if necessary every 5 minutes, and the reading of a dial which is recorded manually. Normally a scientific crew of 4 is carried. Eight records are obtained, for F, I, magnetic heading, gyro heading, optical heading, photo-electric heading, and the remainder for navigational information. "Ground" speed is measured by a radar Doppler effect, both longitudinal and transverse. This is based on reflections from wave surfaces, and would not work on a smooth sea. Milage made and drift are automatically computed and these are combined with azimuth information to give north and east components and positions.

Results show that world magnetic charts are reasonably accurate, but substantial local anomalies occur. Variation of field with height seems more than would be expected from a dipole law - in some cases the gradient increases with height.

National Aeronautics & Space Agency (Skillman, Heppner)

A Rubidium vapour magnetometer is being developed for rockets and satellites. This fits in a cylinder about 4 ft long, and 6 in. diam. The light source is Rubidium vapour, polarised by coils around the bulbs. An interference filter is used to give monochromatic light which is then circularly polarised by a quarter-wave plate and passed through a rubidium vapour chamber to an optically sensitive silicon detector. In the original model, the frequency of the currents was measured. In a later model, there is a coil around the chamber, not quite parallel, and currents are used to induce variations in light intensity by a precession effect. A slight transverse component is necessary for this. This induces self-oscillations. Frequency is measured by a 10-cycle frequency or phase modulation amplifier with a 1-cycle band pass. When this passes through the critical frequency, a phase change of 180° occurs, and gives a marked cross-over on the phase detector. A servo-mechanism is used to lock on frequency. This measurement gives an accuracy equivalent to about 1/5 gamma. This has advantages over the proton type, as it is not seriously affected by gradients, the high frequency (about 175 kc) permits more frequent measurements, and it can be used for very small fields. He thinks observatories should now adopt rubidium vapour magnetometers in preference to proton magnetometers. A different method of recording would be required for observatory use.

Wisconsin University (Sanker Narayan)

A vertical balance was used in conjunction with gravity measurements on field traverses. They are now using a proton magnetometer, purchased in England for £700. This was designed by Hall, an archaeologist, and is manufactured by a firm called Precision Instruments or a similar name. It consists of a cylindrical head on a probe with a handle about 4 ft long. The reading apparatus is in a leather case, about 15" x 15" x 4".

Rand Corporation, Santa Monica, California. Department of Planetary Science (Vestine). Vestine (1959a) is working on isochasms of aurorae and conjugate points. He has used a computer for calculating heights of surfaces of equal total force, and the field at various heights to several earth radii. His two publications on the earth's field and its variations are to be reprinted soon. He has used a computer for integration in auroral studies. Pioneer IV, the moon shot rocket, shows that van Allen radiation persists, although decreasing, to about 14-15 earth radii; only background radiation is recorded beyond this. No sign of beams from the sun has been found. The moon's magnetic field is less than 60 gammas according to the Russians. Vestine predicted less than 20 gammas. Noctilucent clouds are seen in the northern hemisphere, mainly near midsummer, in the twilight zone, very high at latitudes usually from 45° - 62° N. A recent report quotes 40°. Only one report has been given of this phenomenon in the southern hemisphere, from a ship. Vestine is chairman of the committee for world magnetic charts. Recommendations on a permanent service are under consideration. Recommendations for world coverage by the Russians are for 200-km separation of traverses, and 200-gamma contours; probably 400-km separation will be adopted. In Antarctica even this may be difficult to achieve. He has prepared a review article on magnetic storms for publication in "Science" (Vestine, 1959b).

PALAEOMAGNETISM

U.K. Geological Survey, Bullerwell. An attempt was made to determine the age of rocks *in situ* by a dip survey over the area. This was not very successful, particularly where gravity anomalies are large and local.

Cambridge University

Magnetometer is similar to that at ANU but appears somewhat simpler. An astatic magnetic pair is separated by about 10 cm. Effects of heating and demagnetization are tried on all specimens. Browne believes early investigators were lucky in finding consistency in the results of their observations. More recent measurements are apparently not so consistent.

Meteorological Institute, de Bilt

The palaeomagnetometer consists of an astatic pair with 10-cm separation hanging from 3-denier nylon thread (7 microns diameter) in a glass enclosure about 2'6" high enclosed by caneite or insulating material. The factor of astatization is about 1/1000. Samples of irregular shape are used; their volume is measured by immersion, then the specimen cast in a plaster block while oriented in its original attitude. The block is placed at a certain distance from the astatic magnets according to its magnetic strength, and is measured in 8 aspects for induced and remanent magnetisation for each component. Specimens are then "cleaned" by A.C. and measured again. For each rock type, tests are done to determine the strength of demagnetising field desirable. Twenty gammas or so local disturbance (due to trains) does not affect the measurements seriously; magnetic storms do. Accuracy is 10^{-7} emμ. The effect of irregular shape cancels out, as has been proved by comparison with cut cubes.

Institut de Physique du Globe, Paris. Observatoire du Parc St. Maur

Thellier is in charge, but he was absent, and I was shown around by Leborgne. One instrument consists of 4 coils, the inner two being in opposition to the outer two. The sample is mounted on a plate in the centre and is rotated by hand about a vertical axis. The coils are in series so that time-changes in the magnetic field cancel out, but the effect of the sample is much larger on the inner coils. The coils are connected to a galvanometer. Plaster is set on the rocks in situ, directions are marked, then the sample is removed with the plaster. Irregular shapes are used, but if magnetisation is strong the shape can have an appreciable effect in long narrow specimens. The measurement gives the permanent magnetic moment, which is measured in 3 directions.

For susceptibility, 4 smaller coils are set inside the big coils. These are again connected in series and opposition. A current induces magnetisation in the sample but has little or no effect on the larger coils. Small coils are used at one side to adjust to zero the effect without a sample. Samples are weighed (volume is not measured), so the answer is in (gauss-cm/g ?). The plaster is removed for this purpose.

In a new instrument under construction, samples will be rotated automatically 5 times per second and the resulting signal amplified. Drive is by an electric motor below the floor. The outer coils are larger than the inner ones. Difficulty of balance prevents the use of higher frequencies. The apparatus is enclosed in a gauze shield.

Another apparatus consists of two long coils and a 3-magnet astatic system. (Fig.8). The sample must be cylindrical, and is introduced into the coil near the middle magnet, which has twice the moment of the others. Powdered samples are used in cylindrical containers, about $1\frac{1}{2}$ cm diam., 4 in. high. Samples are stacked for a few days with their magnetic axis parallel to the earth's magnetic field, measured, then stacked again for a few days in the opposite direction and remeasured.

A heating apparatus is used mainly for studies of the effect of fire on clay and soil. Combined reduction and reoxidation changes the crystal structure of Fe_2O_3. This is used for tracing archaeological remains by differences in magnetisation of the soil. Anomalies up to 50 gammas or so are found.

Ottawa Dominion Observatory

The palaeomagnetic instrument consists of 3 large coil sets, each with 2 separate coils, mounted at right angles, to give zero field at the centre. A fluxgate detector is located near the centre, and this gives extra current in one set of coils to compensate for time variations. A light beam and scale are placed about 6 ft distant. A suspended magnetic pair is used. Samples are cut to discs and introduced below the magnet to a given height. Sensitivity is 4.5×10^{-8} gammas/mm scale deflection. The height of the sample can be adjusted by a collar on a rod. The operator stands near the instrument and watches the scale while introducing the sample. Only total magnetism is measured, not susceptibility. No "cleaning" is done at present, but a furnace is being built.

University of California - Berkely, (Prof. Verhoogen)

Specimens are rotated at about 100 c/s. Cylindrical specimens are used; with height equal to diameter. They are set in cubes, and are measured in 6 directions. The signal is balanced against the signal from a rotating reference magnet, whose relative angle and amplitude are adjusted. Accuracy is about 10^{-5} only. They have plans for a better model in which the specimen is supported by venturi forces, and rotated by a turbo-mechanism at 300 c/s or so. The signal is measured by a phase discriminator, using a square wave, adjusted so that the output voltage is the same as for a zero signal. A reference signal is obtained from a photo-electric cell, energised by a lamp inside the rotor whose circumference is half black and half clear. Plans are for a three-component photo-electric equivalent of a "magslip" for angle measurement. Noise level is high in the laboratory, particularly at 60 c/s. A pressure and temperature device is used for testing magneto-striction theory but no effect can be measured. He believes that the position of palaeomagnetic theory is rather confused at present. There is not enough evidence to support continental drift. It is more probable that large polar excursions, comparatively rapid, occur about a mean position roughly the same as at present. Pre-Cambrian data don't support continental drift. A review article is to be published soon by (Coxon?).

6. SEISMOLOGY

Cambridge (Ref. 8.iv.). Dr. Stoneley was absent and the seismographs were not recording. Short-period Benioffs were installed in an underground vault, and an amplifier and hot-wire recorder were in a ground floor room. They are mainly interested in microseisms. The site is 2-3 miles from town; there is light traffic only on the road.

Meteorological Institute, Kew. Dr. Stewart showed me the vault (the seismologist was away). They have Galitzin seismographs in an underground vault, with a separate chamber for galvanometers and recorders. Seismology is a side-line to meteorology - no research is done, only standard bulletins are issued. The site is about 1/4 mile from a main road.

Institut Royal Météorologique de Belgique, Uccle & Dourbes

At Uccle. (Dr. van Gils). There is a 3-component Wiechert, and also a Galitzin seismograph. Routine reductions only are done. Weight paper-drives have been replaced by synchronous motors, and smoked paper is being replaced by an electromagnetic transducer tele-line to a visual recorder in the office. The only staff is Dr. van Gils and one assistant.

Dourbes (Ref. 8.v). More sensitive seismographs are installed here - Askania short-period and long-period (similar to Sprengnether type and Galitzin type). The vault is at the end of a tunnel into a hill from the main office. Operation is satisfactory, and no serious trouble has been experienced.

Institut de Physique du Globe, Paris. Parc St. Maur.

Dr. Thellier was not present. The seismographs installed were a Wiechert double horizontal, recording on smoked paper; 2 horizontals which looked like Galitzins, and verticals which looked like Grenet. Leborgne and the other person who changes the records didn't know much about them.

Dominion Observatory, Ottawa (Hodgson, Willmore)

The first commercial model of the bridge (Willmore, 1959) for testing seismographs had just been delivered. It was proposed to use this about once per year at all observatories. A slow oscillator was required for use with this - the one in use generated a square wave, which was converted to a triangle, and then a sine wave (Fig.11). The purity could be tested by double differentiation.

Any seismometer-galvanometer combination can in theory give the same results if the geometric mean of the periods is the same. This has been proved by Grenet and Coulomb.

Magnetic recording. Willmore long-period seismometers and galvanometers are used. These have a tendency to drift, and are subject to temperature effects. A servo-mechanism was used to compensate drift - it operates only while the time-mark breaks the record, and there is no signal on the galvanometer. Maximum speed of re-centring is about 2 mm per day. A light beam falls on a prism, and is split and falls on two photo-electric cells. Mixing circuits are available to combine components and determine direction cosines of arrival; also filters are available for frequency analysis. It is proposed to set the equipment so as to bring up special effects, such as theoretical S-waves through the core.

Hodgson is working on dip-strike of fault planes and movements (Hodgson, 1958 and other papers). The method gives an ambiguous solution, as the 2 planes determined are interchangeable. The Russians claim they can resolve this using S waves. The chord common to two intersecting circles representing each plane gives directions consistent with grain of country in New Zealand, Tonga, and South America. In Japan, 2 directions of motion are found.

Lamont Geological Observatory, Columbia University, N.Y.
J. Brune, post graduate student, also P. Upton from Brisbane).

Most interest is in very-long-period waves, particularly mantle Rayleigh and Love waves. There are 23 seismograms at Columbia per day, ranging from Benioff short-period instruments to instruments with 100 sec or so period. They have installed, and collect records from, 30/100 sec or 15/75 sec seismograph-galvanometer combinations all over the world. Some stations prepare bulletins from these before sending; others don't. Only long-period waves are investigated at Columbia, and even for this the data are somewhat out of hand. They are considering digitising their equipment to enable automatic treatment, but have not advanced very far yet.

Model seismology - 2-dimensional models (circular) are constructed from plastic and metal. Mathematical relations between dimensions and velocities are used in 2-dimensional models and equivalent 3-dimensional models. They use either a piezo-electric or a spark transmitter to simulate an earthquake shock, and piezo-electric pick-up. Earth models are about 18 in. diameter.

Model studies have also been made on a rod with a discontinuity in diameter. Apparently high-frequency energy is stored before the junction, and dies away expenentially. This may give an explanation for the coda of earthquakes.

Records have been made of waves which pass round the earth by the long way, and around the earth more than once.

Synthetic seismograms have been constructed from phase theory - an example shown to me appears remarkably successful.

A filter galvanometer is used on long-period seismographs to eliminate microseisms at 6 sec.

A moon seismometer is under construction. It has a quartz system, with a long period, and fits in an aluminium can about the size of a beer-can.

<u>Theoretical investigation</u> is being made of dispersion by phase-velocities etc. (Brune, Nafe, and Oliver, 1960). It is assumed that a pulse at the source is composed of an infinite Fourier series. If one period is selected, a pulse of this period travels with the phase velocity, while the energy travels with the group velocity. Where maximum energy is recorded at this period in the dispersed wave-train, the group propagation corresponds to phase propagation of a peak n wave-lengths before the event, where n = small integer or $\frac{1}{2}$ integer (peak or trough). Curves are drawn for n = 1, 2, 3; 0.5, 1.5 etc. Generally all except one give ridiculous answers. Separation of the possibilities is greater with greater distance. A bomb, where a trough is known to occur at the source, is used to give values for phase velocity; this is used in earthquake studies and gives consistent results. This gives information about the direction of motion at source, apparently consistent with fault-plane solutions.

<u>U.S. Coast & Geodetic Survey</u>, Washington

Instruments include Benioff reluctance and moving-coil, Sprengnether, Wilson-Lamison, vertical and horizontal. The Wilson-Lamison is a simple hinged weight (plate 6" x 6" x 1/2" approx.) vertically supported by an iso-elastic spring, with an attached coil moving in a cylinder between magnetic poles. Sensitivity is adjusted by a shunt resistance, which also affects damping. There is no separate adjustment for damping, It is used with a G.E. standard 1.5-sec galvanometer; the seismometer has a period of 1 sec for the vertical, or 3-10 sec for the horizontal, adjustable by tilting longitudinally. A sharp peak occurs at about 1.3 sec for the vertical, with maximum magnification of 25,000; if a lower sensitivity is used, more even response is obtained. Crystal clocks are now used for timing, and they aim at 0.1 sec. accuracy. I obtained a circuit diagram (transistorised) for putting WWV time pips on records. They have a film recorder for Benioffs, and find some advantages and disadvantages; elaborate tuning fork control is used to ensure even drum speed. They are considering tape recording and playback, but nothing has been done yet.

A shaking table is driven by a generator with a frequency range from 0.01 to 100 c/s , which will give sine, triangular, or square-wave output. The table will take Sprengnether or Wilson-Lamison seismometers, but not Benioff moving coil (or reluctance?). One table is used for horizontal motion, and one for vertical. Motion of the table is recorded optically by rotating a mirror by a lever system, and the galvanometer records alongside this. So far the table has been used only in Washington. He thinks the Willmore system is preferable because "on the spot" calibrations can be made. A magnification of 5 x 105 has been measured for a Benioff moving coil.

<u>Epicentre determination</u> (Mr. Brizee).

<u>Present method</u>. All reports for each 'quake (or at approximately the same time) are listed by a clerk on forms, 1 sheet for each 'quake; if possible the S phase is listed also. If reported by 5 or more well-distributed stations (especially in azimuth), including one U.S. station, an epicentre is determined. Radii are drawn from the various stations, and more reliance is placed on accurate stations or close stations. Gutenberg and Richter tables or charts are used. A monthly review is made, the P phase being calculated for all stations, and the observed time being checked.

A new method...is to be instituted soon, using IBM650. The relevant stations and arrival times are punched on cards. Constants for the stations used are red on to a memory drum. The station with the earliest recording t_o is selected, and a curve $V_o t_o + at^2$ is fitted to all observations used. This is a first approximation to a travel-time curve, and V_o, a, are determined experimentally. This procedure seems to fit for intermediate distances, but the formula may need to be more complicated for universal application. From this, and an expression for distance from epicentre including allowance for focal depth, a solution is made for origin time, epicentre, and depth. Then arrival times of P at the stations are calculated from Gutenberg and Richter travel-time curves, and residuals from observed times are recorded. A least-squares solution is made from these for error in the first epicentre. They want future phases to be given to 0.1 sec., even if the timing is not as accurate as that, as this will enable statistical analysis of results and determination of relative accuracy of stations, and of consistent errors, if any. Expected accuracy of determinations is $\pm$ 0.5 sec., and $\pm$ 5 km in position and depth.

Research. Dr. Carder has a scheme for recording by an array of 200 or more geophones in a pattern. Incoming signals are to be weighted in a similar way to a Fourier transform, to emphasise signals around 1 sec and cut down noise level to about 1/3. Geophones would be separated by about 200m, and the total area of the array would be about 3 km square. Total cost is estimated at about $200,000. This has not been tried yet, but he enquired, if this ever works, whether U.S. could install an array in Australia, and B.M.R. operate this for them.

Strong-motion seismographs have been developed by Carder for study of damage on buildings. These have been used with underground explosions of much greater than one kiloton (Carder and Cloud, 1959). Results seem to indicate that ground movement can be predicted as a function of time within a factor of 2 or 3. Carder is awaiting Doyle's (and our) results before publication of his results from nuclear explosions. Interesting effects occur near the 20° discontinuity. It seems that a velocity of 8.2 km/sec may be recorded right through, with a possible curve connecting into the next branch. A doubtful Rabaul result affects this interpretation.

Brizee (?) would like to study the relation of envelopes to magnitude of earthquake and distance from epicentre. U.S.C.G.S. have 20 years records from 20 stations.

Kermadecs-Tonga is the most active seismic area; New Zealand is comparatively quiet. A peculiar effect occurs at a station on the west coast of South America, which does not record 'quakes, even quite large ones, from an area in Central America and northern South America.

Carder thinks he may suggest that U.S. supply a 3-component Benioff and a 3-component long-period seismograph for Darwin or Alice Springs. He would like to know whether we could supply a vault and observers to operate this.

For results of several years investigation of microseisms, see Ref.6.iv. Carder believes that IGY procedure for scaling microseisms gives no useful information.

U.S. Geological Survey

Seismic work has been considered for detection of explosions - Fourier analysis of pattern records, and auto- and cross-correlation of seismograms, have been used to give the shape of the pulse and direction of motion at the source; also surface wave transmission has been studied where several layers exist.

This is in association with Lamont Geological Observatory and U.S.C.G.S. Plans are only being considered at present, but programmes will be developed if the plans are adopted.

Wisconsin University (Steinhart). Crustal studies.

Shooting is done in lakes using their own specially developed equipment, geophones, and amplifiers. Quiet sites are selected for recordings. Shots are less than 1 ton, depths are usually 10-50 ft depending on the charge. The depth is chosen so that the bubble just breaks the surface, and this eliminates the "bubble-pulse". See summary report for some details of method (Ref.6.iii).

They have found a crustal thickness of about 35-45 km under the Rocky Mountains, which is a smaller thickening of the crust than predicted by isostasy. He would be interested in our results from Alps. He believes that intermediate layers do not exist generally.

Antarctic - Woollard is compiling all available data to produce a map of Antarctica summarising gravity and seismic results. He claims that local seismic shots show good correlation with depths calculated from gravity.

See also Refs. 6.i and ii; section on gravity, and Woollard (1959).

Pasadena Seismological Laboratory (Press, Benioff, Gutenberg, Healy, Blayney; Hatherton arriving any day from New Zealand).

Investigations of crustal structure have been made by combination of explosions, surface wave dispersion, and gravity. Press concludes that an intermediate layer of thickness 26 km and velocity 7.6 km/sec exists in California, and the depth to the M-layer is 49 km. Refraction cannot give low-velocity layers - if the results of dispersion studies disagree with refraction, low-velocity layers must be present. He recommends shooting small shots with careful instrumentation - otherwise one cannot disprove the existence of an intermediate layer. ("Small" = 2 Kiloton, 50,000 lb etc.). He is interested in the low-velocity mantle channel, and a study of local variations is proposed. Also extra-long-period waves are being studied by Benioff. A "Ground" pulse was recorded from the recent Montana earthquakes. They propose to locate strain gauges across fault planes. These use interferometric measurement of strain, with 2 prisms, one at the end of a long quartz tube, the other "fixed"; these are used to calibrate an electrical (capacity - frequency) transducer, which is used with a D.C. detector. A microscope capable of measuring distances of less than a micron is used to measure fringes. The separation of the blue, yellow, and green lines of mercury gives the absolute separation of the plates. The instrument drifts at present and this has to be overcome yet. They propose digital recording of earthquakes.

They have a Bendix intermediate-size computing machine with a memory of 2500 words, and an additional magnetic tape store, which can adapt programmes from various coding languages. The input is perforated tape - but a punched card adapter is available. Cost is about $50,000 + $1,000 per month service. Cheaper prices are available to teaching institutions. It has an extremely simple language, which involves slower calculations but saves time on programming. This is desirable for comparatively short non-routine problems. The machines is used for Fourier analysis, cross-correlation, synthetic seismograms, and initial pulse studies.

Benioff seismographs are kept in "sleeping bags" with fibre wool insulation to prevent convection currents. Horizontal torsion seismometers are still used for magnitude determinations of local 'quakes - see Gutenberg for long distance (greater than 16°) and Richter for near (less than 6°) magnitude determinations. (Refs. 6.v & vi). Gutenberg determines magnitudes only for 'quakes of 6.9 or greater.

A Worden meter has been used for profiles with 1/4-mile stations across faults etc. - no routine interpretation has been developed yet. Results are treated manually. They are studying the Basin and Range area.

They would appreciate amplitude measurements. They calculate these from Perth, as they have the instrument constants. Press would like to study surface waves on the records from Wilkes if we agree. I said we would issue normal bulletins (Pasadena will do this if required). They are also working on the moon seismometer in conjunction with Lamont.

Tripartite stations have been set up in a 600-km triangle, in California-Nevada, for study of surface waves. They have about 20 out-stations, which merely change records and send in for developing weekly, and check the time etc. A crystal clock is now used for timing. A new tuning-fork-controlled chronometer has been obtained. This is highly portable, accurate to about 0.1 sec per month and can be read to .01 sec against WWV ticks.

Model studies are made, using a barium titanate transmitter, and a flexible double-strip detector. An aluminium plate is used to represent the mantle, and two plastics are used for the crust, using different velocities so as to represent an intermediate layer. The thicknesses are much greater than natural scale. The plate is loaded in the centre to stop continued P reflections. They study waves with wavelength greater than the thickness of the plate so as to get a two-dimensional effect, studying dispersion of surface waves at various distances.

Their seismographs record on film as well as paper, and also on visual recorders. A special low-sensitivity galvanometer is used on one film channel for strong motion. Signal strength is much higher on the campus, which is on sediments. The noise-level is also higher. The signal-to-noise ratio is better on granite. Gutenberg is studying P diffraction in a shadow (Gutenberg, 1960). Richter was in Japan.

<u>University of California - Berkely seismograph station</u> (Dr. P. Byerly)

The Press-Ewing seismograph gives trouble with tilts in the horizontal components during the daytime if used at a period of 30 sec. No trouble occurs at night and week-ends. It is surrounded by thermal insulation and no trouble occurs with temperature effects or with the vertical component. The natural period varies with the amplitude. He believes this may be true for most seismographs, or possibly for electromagnetic types only. He does not believe universal response curves. The magnification of Wood-Anderson seismometers is in doubt - shaking table tests give less than 2,000. He does not like Gutenberg's new magnitude scale. His suggestion for the explanation of the anomalous phase recorded in Melbourne from Banda Sea 'quakes is that a T-phase occurs under the sea path, then P or S is excited afresh at the continental border. After re-interpreting relevant data (Byerly, 1956), he believes the Conrad discontinuity is present in America and is also present in Europe but may have different velocity and depth.

The mechanism at the source of earthquakes has been studied. Fault slip may account for many earthquakes, but he believes other mechanisms are necessary to explain others.

San Francisco is on a narrow stable block, with earthquakes along the boundaries and outside but not within. A 6-sec galvanometer has been used in series with a long-period galvanometer as a microseism filter.

7. GRAVITY AND MAGNETIC INTERPRETATION

Shell Co., The Hague (Kok replacing de Bruin, Hoffner)

Programmes are available on the IBM650 for the following processes :-

Second vertical derivative, by Hubbert-King or Brunk's formula, and also by the Henderson and Zietz (1949) formula.

Residuals and regionals by the Griffin (1949) method, or by polynomial methods using second- or third-order polynomials and a five-ring or nine-ring procedure.

Downward projections, either two or three-dimensional.

Hexagonal or square grids are used for derivatives and residuals.

All the information from rows of grid points required for the computation are fed into the computer, which has 2000 addresses. Up to 195 figures can be used for each row. Answers are computed for each point along one row, the rows are then moved over one place, one row is cleared out of the machine and a new one fed in from the other side. The process is repeated continually.

The usual procedure for residuals is that data are interpolated at the grid points from points of observation, and the regional is calculated at the grid points. Regionals at observation points are then interpolated and the residuals calculated at the observation points. However, residuals can be calculated directly if necessary.

Downward projection has been tried on aeromagnetic anomalies only. Large oscillations resulted owing to noise in the original data, in spite of smoothing twice at each step in the projection. This process is considered of doubtful value, at least beyond a depth of two grid spacings.

Second derivatives are calculated for aeromagnetic anomalies only for comparison with the Vacquier method of interpretation (see Geol. Surv. America Mem. 47, Vacquier et al, 1951). In this method, anomalies are calculated on the assumption of induced magnetism in block features for various inclinations, widths and lengths.

The formulae used are as follows :-

Second Derivative

$$d^2T/dz^2 = 5.4440T - 1.0\sum T_1 + 0.1\sum T_2 + 0.0074\sum T_3 \quad \text{(Brunk)}$$

$$d^2T/dz^2 = 1.06060T + 0.09596\sum T_1 - 0.033839\sum T_2 + 0.06566\sum T_3 \quad \text{(Hubbert-King)}$$

These use a hexagonal pattern, with 6 points on circles of radii 1, 2, and 3 grid spacings.

$$d^2T/dz^2 = 6T_0 - 2\sum T_1 + \tfrac{1}{2}\sum T_{\sqrt{2}}$$ (Henderson & Zietz, 1949)

This uses a square grid, with 4 points on circles of radii 1 and 2 grid spacings.

Regional Polynomials

$$G = \sum (a_n \sum_m g_{mm})$$

where g_{mm} is a value on a circle of radius r_n as determined from M points on the circle; a_n, r_n and M are given in the following table for n=1 to 5 and n=1 to 9 (Fig.19).

n	r_n	M	a_n (5-ring)	a_n (9-ring)
0	0	1	0.15429	0.07483
1	1	4	0.12571	0.06803
2	$\sqrt{2}$	4	0.09714	0.06122
3	2	4	0.04	0.04762
4	$\sqrt{5}$	8	0.01143	0.04082
5	$2\sqrt{2}$	4	-0.07429	0.02041
6	3	4		0.01361
7	$\sqrt{10}$	8		0.00680
8	$\sqrt{13}$	8		-0.01361
9	$3\sqrt{2}$	4		-0.04762

The answers are tabulated on special paper in the form of a square or hexagonal grid and are reduced photographically to a suitable size for contouring.

Gravity effects of 3-dimensional features is done by a cylindrical integration formula, using a hexagonal distribution of points, each representing a 60° sector, and rings between radii 0, 0.5, 1.5, 3.0, 5.5, 8.0, etc.; depths at the intermediate points 0, 1, 2, 4, 7, etc. are used. Calculations are made at alternate points of alternate rows only, giving a square pattern.

This was tried on a Ferranti computer, but abandoned for an optical method. Six rings are not enough and square root calculations are too slow. If a faster computer were available with larger storage, they might reconsider this.

Calculations of theoretical gravity tables were carried out by machine.

Downward projection for 3 dimensions, 6 points on 6 concentric circles are used.

for 2 dimensions, 7 points each side of the centre are used.

Smoothing is applied by least-aquare fit to 5 successive points centred on P to a quadratic curve. This is applied twice after each step. Time taken is about 6 minutes for one process on an area with about 50 x 40 grid points.

Polynomial regionals are calculated by Simpson's (1954) method. 11 x 11 squares are used with 2/3 overlap between successive squares. He considers the Griffin (1949) residual method is about as good as any for most purposes, but other methods are not much harder on machines.

Interpretation of total intensity anomalies

A simplified method is used for calculating pseudo-gravimetric anomalies (Ref.7.viii) from magnetic total-intensity profiles across two-dimensional features.

First a baseline is drawn for T = 0 (see Fig.20). This may be difficult to fix if any neighbouring disturbance exists. Standard-type anomalies for various features help in fixing the baseline - for some features it may be nearer to the minimum than shown in Fig.20. Then maximum and minimum values of T are measured and a horizontal line is drawn at an ordinate given by :-

$$T = T_{max} - T_{min}$$

Let x = o where this cuts the anomaly curve between the maximum and minimum. Then the horizontal and vertical components of the pseudo-gravimetric anomalies are given by :-

$$H = \frac{1}{2}\left[T_{(+x)} - T_{(-x)}\right]$$

$$V = \frac{1}{2}\left[T_{(+x)} + T_{(-x)}\right]$$

As a check, the maximum of one curve should occur at the same x-value as the zero or the point of inflection of the other one. If this is not the case, another baseline is tried.

When the pseudo-gravimetric anomaly curves have been constructed, draw a tangent to the curve at the point of inflection (Fig.21). Let this cut the horizontal lines through the maximum and minimum of the curve at P and Q. Let P' be the projection of P on the line through the minimum (see Fig.2). Let P'Q = 2z', and let the distance from the maximum to the point of inflection be x_a. Also let z be the projection on the x axis of the distance between the maximum and the minimum.

Then from the ratios x_a/x and z'/z, the shape and depth of the feature can be estimated.

For a circular feature, the interpretation is based on the east-west profile through the point of inflection on the north-south profile.

Thousands of type anomalies have been calculated on IBM650 for various features, based on the assumption of induced magnetism. These are a development of the method of Vacquier, Steenland, Henderson and Zietz (1951). These include a single pole, a dipole, a line of poles, vertical dykes, inclined dykes dipping 30°, 60°, 90°, 120°, and 150°, horizontal plates, and step faults. Anomalies have been calculated for magnetic dip from 0° to 90° at 5° intervals, and for various depth/width ratios. Instead of calculating the anomalies for various directions of strike (i.e. angle between magnetic north and strike of feature), it has been found sufficient to determine a factor for correcting results for strike. No allowance has been made for possible permanent magnetism.

Interpretations have usually been done on individual isolated anomalies to give depth to basement. No attempt has been made to correlate individual anomalies with gravity anomalies.

A routine interpretation procedure has been developed in the form of a family tree. For example, the first question is whether the anomaly is circular or elongated. If it is circular, various parameters of the curve are investigated and according to the results, a more detailed investigation of a certain type of feature is made. A similar procedure applies for the elongated anomalies. Checks are made periodically to see whether the interpretation is satisfactory.

<u>Compagnie Générale de Géophysique, Paris</u> (Geneslay, Baranov, Kunetz, *et al*).

First vertical derivatives and rarely 2nd derivatives are calculated in gravity work. Residual and regional anomalies are used. Type anomalies are calculated from contour maps. Sometimes upward and downward continuation are used, but not often. A triangular grid is used, with 2 co-ordinates at 60°, for all computations - this gives 6 points on circles with integral ratios of radii.

Profiles for gravity anomaly of a block have been calculated for parameters of depth, and ratio width/depth, and density contrast; these are plotted on log-log paper and give values of the half-width of the anomaly and of *g*.

Reductions to Bouguer anomaly and terrain correction are done in the field. Isostatic anomalies are done if at all by the Bureau Gravimetrique Internationale.

"Pseudo-gravimetric" anomalies calculated from total intensity magnetic anomalies are now referred to as "reduction of poles". Programmes are available for processes similar to those used for gravity; the points are weighted also for azimuth where required (I didn't get much detail of this).

<u>U.S. Geological Survey</u> (I. Zietz, Gordon ?, J. Meuschke, Dempster, R. Henderson, M. Kane).

<u>Interpretation of aeromagnetic anomalies</u>. Individual ones are selected which are believed to be mainly induced. Interpretation is done principally by the method of Vacquier *et al* (1951). Zietz believes that permanent magnetism affects some anomalies, but these are in the minority and can be distinguished. Contours are drawn for depth of basement; I saw several examples of agreement with gravity and drilling, within 10-15%. Dykes, etc. in the basement generally give magnetic and gravity anomalies with different ratios of amplitudes and sometimes opposite signs. Pre-Cambrian sediments have little or no magnetic anomalies (perhaps 10 gammas at 500 ft). Other (sometimes large) gravity anomalies are unexplained. Volcanic rocks can be mapped, as they always have high magnetic disturbance, and if thick, high gravity.

<u>Model studies</u> have been made over horizontal plates, with susceptibility 0.06, high enough to introduce demagnetising effects which are absent in rocks of lower susceptibility. Hence rigid calculations of effects of plates without the demagnetising effect were made so that correction for this could be made to model experiments (results not published yet).

Gravity field procedure varies and no uniform presentation of results is used to date. It is hoped that machine reduction will counteract this. Negative anomalies generally occur over granite, with an exception of one area of pre-Cambrian. Heavy minerals in reasonable quantities appear to be iron or magnesium compounds. Projects are in progress in the Basin and Range Province, the Cordillera, and the Appalachians.

Perforated tape input is used for machine computations. Downward continuation can be applied to either total intensity or gravity at $n = 1...5$ grid spacings (each operation is performed on original data). Also 1st or 2nd vertical derivatives can be obtained at any level. R.G. Henderson is submitting a paper for publication shortly in "Geophysics". He uses 10 circles on a square grid with radius up to 25 grid spacings. He believes 2nd derivative is more accurate than with Henderson and Zietz previous formula, which was better than others (Nettleton, 1954). No trouble has been found with 45°-striking anomalies or with wild oscillations of downward continued data. Original data are not generally smoothed. Some oscillations may occur, but a mean can be drawn through these. If the grid spacing is too close, the oscillations may become large. He recommends a grid about 1/4 of the depth at which sources are expected. Downward continuation is obtained by solution for a polynomial from the upward continuation formula.

Terrain corrections are calculated out to a little beyond the Hayford K zone. A square grid is used as shown (Fig.22). Mean elevations are written for the whole area at the corners of 1-km squares. For inner (1-km) squares, for each station whether on corner, centre or elsewhere, the computer obtains a weighted mean elevation of 4 points within the squares relative to the station, i.e. as if a grid centred at the station were overlaid on the terrain map. Each square is approximated by a cylindrical segment, of mean radius r, with outer and inner radii $r \pm dr$. Original programme had tables for square prisms fed into the machine, but reference to the tables was slow. Within the central prism, an improvement has been made on the zone method by using wedges - the square is divided into 8 sectors (Fig.22) and it is assumed that the slope is uniform within each sector. The effect of each wedge is calculated by approximating with a cylindrical sector, whose top surface is part of an inverted cone and whose volume equals that of the square wedge. This is accurate to within 1% for slopes up to 30°. In extremely rugged topography, the sectors are subdivided (Fig.22) and tables are prepared for each "zone" mean height. On Burroughs 204 the calculation takes about 4 minutes per station and costs about $4.00. Costs will be less on a newer machine. Also a "reject" criterion is being built in. The machine tests each square height and if within a prescribed limit such that the effect is less than .001 mgal , it will not compute, but records "zero". This limit could be raised for some work. It is estimated that this will save 50% machine time in most areas, up to 85% in flat areas, which at present are not computed. Cost should reduce to 50c per station.

Routine reduction of field results. Observations will be punched into cards at H.Q. or field H.Q. (Denver or Menlo Park). Calculations will be done at Washington and will include provision for the terrain correction as above and also Bouguer anomalies for 4 selected densities. Provision is made for expansion of the terrain correction scheme to include the total correction - probably a map will be drawn for whole country for outer zones if the effect of elevation of the station can be allowed for satisfactorily. Results can be calculated in one day and the party chief advised (except on pay days?). Zietz believes in keeping field results up to date so as to modify the survey as necessary.

No routine reduction of airborne magnetic results or adjusting of loops is done by machines yet. The latter is not done by least-squares except in the topographic section, where elevations are adjusted by the electrical analog method.

Analog method, optical, is planned for computing gravity anomalies of 2 and 3-dimensional features using the same machine as that owned by Shell (q.v.) but they will use "dot chart" graticules with a black background and transparent dots, and measure total light through the dots, instead of shading sections.

U.S. Coast & Geodetic Survey. An IBM650 is used for geodetic computations, 60% (e.g. adjustment of triangular network, etc.), geophysical and other technical 5-10%, and the balance on accounting, etc.

Geophysical uses :-

Gravity - routine reduction of data

in some cases only, deflections of vertical calculations

Magnetic - reduction of hourly values, means etc. preparation of U.S. and world charts

Gulf Research and Development - aeromagnetic (Fink)

The fluxgate type is still used with Shoran navigation and some photographic navigation (mainly as a check). Interpretation is usually approximate at first, based on half widths and similar rules. For more accurate interpretation a assumtion is made of a vertical tyke of unknown magnetic inclination. Five parameters are used to describe this - depth from 'plane, width, magnetic strength, magnetic direction and location of centre. These are varied to fit, using a formula of the form

artan (.......) + log (.......)

If the zero anomaly level is known, these can be separated into odd and even functions corresponding to V & H. A high-speed computing machine is not used in these computations. Second derivatives are commonly used. He believes that areas with rugged anomalies and sharp lines dividing them from smoother areas, may have tectonic significance. Individual anomalies are no longer considered significant in themselves.

Magnetic anomalies are usually considered to be due to pre-Cambrian; sediments and igneous rocks are not separated. But some areas are "dead" (i.e. no anomalies are recorded), yet this is not believed due to a deep sedimentary section. Sometimes a negative (or positive) anomaly, approximately circular, is surrounded by a series of "highs" (or "lows") - sometimes by a double ring (Fig.23). He believes this may be due to a concentration of magnetic material in certain zones during solidification of an intrusive plug.

8. EXPLORATION SEISMIC

Shell Co. (Hague) - seismic (Moldenau). Variable-area profiles are photographed down and reproduced as a cross-section. A correction can be applied at one depth for each trace for step-out; weathering corrections etc. are also applied. Time cross-sections are drawn, also contour plans. Migration and interpretation including variation of velocity within an area if necessary are applied to the contour plan. No magnetic recording is used yet.

Compagnie Générale de Géophysique, Paris. Seismic computations. Calculation of synthetic seismograms (Ref.7b.ii) is done from continuous velocity logs (Ref.7b.iii). It is assumed that all reflectors are horizontal; the reflection coefficient is related to the derivative of the C.V.L. Actually the C.V.L. is "sampled" every 6 msec for digitising, and the reflection coefficient is proportional to $(V_1 - V_2)/(V_1 + V_2)$. A seismogram is then calculated for a square-wave pulse. This is similar to the reflection coefficient curve. For other-shaped pulses (Fig.12) the trace is a cross correlation of the pulse with the trace for the square wave. This is calculated for different widths of pulse to simulate effects of filters. The first calculation is for direct reflections only, and shows many discrepancies with the actual record. Next, a seismogram is calculated for complete multiple reflections at all interfaces - this gives a picture much nearer the true seismogram. By this method, distortion of reflections by multiples and even cancellation, can be detected. The latest stage is to allow for normal move-out, but the number of multiples is reduced to 2nd or 3rd-order reflections (Fig.13).

Calculations of type anomalies have been made for resistivity surveys (Ref.7c.i and iv). A very wide spacing, up to 35 or 45 km, has been used as a special test for IGY. This shows that the resistivity increases to a depth of 10 km in the crust.

Gulf Research and Development (Gardner, Dean, Wuenschel, Schulberger)

Variable-density profiles are used for preference. Recording is done mostly on magnetic tape. Various types of tape are supplied by contractors - replay machines are used to feed on to a standard type. The playback apparatus uses filters and compositors (from several adjacent shot-holes for the same spread). Variable-density profiles can be corrected for weathering (each track is re-photographed separately) and step-out (each track is scanned, and the corrector moves during scanning and reproduction). Diffraction is considered important in the interpretation of faults (Fig.14).

Synthetic seismograms. Dean uses Laguerre's orthogonal functions of type $e^{-f(x)t}$, where x is a polynomial. These have a form with n zeros, where n is the order of the polynomial (Fig.15,16). (See "Fourier series and orthogonal polynomials", by Dunham Jackson, also other papers in references). The series is equivalent to a Fourier series if the time ordinate is transformed from (0 to π) to (0 to ∞). Suitable combinations can be used to simulate normal seismic pulses. Up to 32nd-order polynomials are used - NBS tables are available to 15 only; these have been extended by graphical extrapolation of the network (see Fig.16). These simplify programming of computation of seismograms from CVL records. Simple theory has been published by Peterson, Fillipone, and Coker (1955); this assumes one reflection only at each interface, and no loss of energy on transmission. The information is digitised in steps of .0025 sec, i.e. 400 c/s, as this is shorter than the period of seismic pulses. Wuenschel (1960) has developed a theory for complete multiples. Computations are done on IBM704.

Uses. Synthetic seismograms show that the main energy of a seismic pulse often occurs later than the time position of a layer, and may give information from above an unconformity instead of below. One can distinguish multiples and show how they interfere with genuine recordings. One can evaluate the effect of "ringing", due to a near-surface high-reflection-coefficient layer - this apparently acts as a filter and smooths and spreads reflections from any lower layer; by applying the reverse filter mathematically or by analog, reflections can be brought up. Most energy in multiples comes from surface reflections. The method shows how several layers with wave-length close to that of the pulse can distort simple reflections.

Limitations - CVL is often not available for the top few hundred feet of hole (cased); all velocity changes may not be horizontal and reflection surfaces are not infinite; presumably effect of displaced reflectors, diffraction etc. is not included.

More Uses. Sometimes one may distinguish apparent (RP) events due to noise, and can suggest the best filtering techniques to employ; the method may suggest effects to look for in areas where pinching stratigraphic traps and other features of difficult interpretation occur. In some cases an attempt may be made to find out if the pre-Cambrian occurs below a certain depth. A synthetic seismogram is constructed with uniform velocity below this depth.

The true reflection coefficient r is -

$$(\rho_1 V_1 - \rho_2 V_2)/(\rho_1 V_1 + \rho_2 V_2)$$

(ρ = density); this has been used in a test case where a gamma-gamma log was available. However ρ is generally proportional to V^n and thus $r = (V_1 - V_2)/(V_1 + V_2)$. In the test case the agreement between the true record and the approximate synthetic record was fair; the agreement between the respective synthetic seismograms was pretty good (below normal inaccuracies, noise etc.)

Model studies. (Dr. Wuenschel). 2-dimensional models are made out of a plate of perspex about 3/16" thick and about 4 ft square. The transmitter is a small cartridge, with threads like a harp. These are dipped in a liquid which then solidifies; the threads are fired and leave carbon inside. The cartridge tends to flex when a voltage is applied. This principle is used in gramophone pick-ups. Dimensions of the cartridge are about 1/4" x 1/8" x 1/16". It is attached by grease or glue to the edge of the plate, representing the surface. The receiver is a "needle" about 3/16" diameter projecting from a vertical cylinder. The needle rests on the plate on the end of an arm. A spider chart on cartridge paper is placed under the plate to give co-ordinates of the receiver. The pulse is formed as a double-step, with adjustable separation and relative amplitudes of the two steps (Fig.17). This gives a received signal similar to that shown (Fig.17), depending on filter setting etc. The plate is laid horizontally on soft material, then on an earthed metal plate. Contrasts are made by cuts in the plate, or interleaved aluminium or other metal. The reflection coefficient can be adjusted by the thickness of aluminium. The example being tested during my visit was the diffraction around the end of a horizontal layer (Fig.18). Another model study was diffraction around holes of successively larger diameter. The effect was being studied as the hole diameter becomes large with respect to the wavelength. Frequencies of about 3 kc were used, and the wavelength was about 0.4 in.

United Geophysical Corporation, Pasadena - (Martin, Portwood).

(Mainly exploration seismology). Variable-density recording is used for preference, in conjunction with a strato printer similar to Gulf (manufactured under licence). It can be used for "trace" or variable-area seismograms. Magnetic recording and playback equipment and an analog computer for synthetic seismograms from CVL were not in the office. Dr. Peterson, chief interpreter etc., was not in. They run 6 gravity crews on contract, and use manual treatment of all data - usually residual maps are prepared; the client does more if required. I saw several examples of typical variable-density plots (also others) including fault and diffraction, a fault which was apparently continuous on ordinary traces, a salt dome, and a refraction profile with later events.

9. MISCELLANEOUS

Royal Aircraft Establishment, Farnborough. Radio (Mr. Johnson; Blackband absent).

Radio interferometers for satellite and missile tracking - design and working models have been completed; a contract for 4 sets for Australia is to be let soon (finance has just been approved). Each set has 4 antennae, each consisting of two $\frac{1}{4}$-wave rods at right angles, about 3/8 of a wavelength above ground. Chicken net is spread about 10 ft around on level ground for a reflector. The separation of the antennae is about 50 wavelengths. Standing waves are set up in the cable between the antennae, and these are sampled at 4 points separated by 1/8 wavelength near the centre. The signal from each is fed in turn to an amplifier through a special coded square-wave switching device, which also gates the output. From the signals the sine and cosine of the phase of the standing waves can be deduced. This gives a fine bearing of the transmitter, the approximate position being known. Records for the sine are as shown in Fig.9, with a similar one for the cosine in quadrature, as satellite or other source passes overhead. Their interest is in studying ionospheric scintillations from 4 Black Knight firings - irregularities in apparent path owing to refraction in the ionosphere. Site requirements are not stringent, but reasonably level ground free from buildings is preferred. An ionospheric aerial may be alright in the centre if reasonably symmetrical. Antennae should be approximately the same height. A pre-amplifier is located at each sampling point. Normally the main amplifier is at the centre of the site. The feeder cables must be the same length, and if the amplifier is elsewhere, longer cables are required. The equipment uses 230V A.C., about 1 kW 50 c/s. The site must be calibrated by the sun, preferably with a single sun-spot, or a satellite of known orbit. Irregularities (buildings etc.) can be allowed for in the calibration, but naturally this makes interpretation more complicated. Accuracy is about 1 minute. They claim the equipment is about as good as, but much cheaper than, Minitrack equipment.

The amplifier is in a rack about 3' high, 3' wide and 1'6" deep. A triple pen-recorder records sine and cosine from one direction, sine only from the other. Two sines (or cosines) are sufficient, but the additional channel provides a check on the source of disturbance - terrestrial noise is not in quadrature. Some bursts of energy from the sun appear interesting. Sunspot radiation is about 100 times greater than general solar radiation. He doesn't know whether sfe have any effect. The equipment can be used at other frequencies, e.g. 20, 40 Mc/s, but 108 Mc/s seems most satisfactory.

An alternative method of studying ionospheric structure is with a single antenna, consisting of two quarter-wave rods at right angles, with frequency about 20 Mc/s. This gives a fading pattern due to Faraday rotation of the plane of polarisation. This can count electron density as obliquity increases and additional layers or "holes" in the ionosphere become effective. The centre of the record is easily identified for starting point; this corresponds to the overhead position, where no fading occurs. The envelope of the record is shown in Fig.10. The two records are in quadrature again. The only requirements are two receivers and a recorder. Corrections are needed for change in height of the transmitter.

R.A.E. will require cooperation for only 4 firings, recording for about 20 minutes each time. Equipment will be on permanent loan and may be used for other purposes. (Research in conjunction with Perth University is a possibility).

Johnson may possibly be in Australia in February 1960, and the equipment may be delivered about June 1960. He claims good reliability for the equipment, which uses valves, An excellent handbook about 2 in. thick is provided.

Meteorological Institute, de Bilt. Ionospheric equipment is home-made. It has a range from 2 - 17 Mc/s, and an output of 10 kW peak.

Absorption measurements are made at 2.3 Mc/s; the ratio of 1st and 2nd reflections is measured. Vertical movements are also recorded at 2.3 Mc/s; 3 receivers are spaced about one wavelength apart and the movement is obtained from the difference in time of the 3 signals. Not very successful.

Royal Meteorological Institute, Dourbes. An ionospheric type C2 recorder is in operation (Ref.8.v). This used to give considerable trouble some years ago, but after overhaul and some rebuilding, is now very reliable.

M. Bosset at Uccle discussed interpretation of records and related matters.

M. de Vuyst, O.I.C. at Dourbes, is responsible for operation.

Use is made of an IBM650 for determining medians. Cards are sorted in increasing order for any given parameter, and the number of cards is listed with each value, as well as the running total of the count.

Conference of URSI/AGI had been held during the previous week at Brussels - J. Turner was present, representing Australia.

U.K. Geological Survey (Bullerwell) - gravity, aeromagnetic, airborne radiometric, airborne electromagnetic, ground electromagnetic, self-potential, resistivity, and magnetic methods are used. They also have a 6-channel refraction/reflection seismograph (Swedish).

Airborne work is done by contract and is mostly flown at 1000 ft.

All results are plotted on standard grids (about 1 mile = 1 in. or more) and reduced photographically to 1/4 mile = 1 in. in overlay patterns.

A marked correlation of electromagnetic anomalies with terrain clearance (i.e. radio height-finder reading) has been found. Anomalies of interest are those that do not correlate, as seen by overlay charts.

Aeromagnetic flight lines are generally 2 km apart, and tie-lines are flown at 5 km intervals.

(See also section on gravity)

Overseas Geological Institute. (Masson-Smith). This organisation carries out surveys in colonies and dominions on request; the colonies pay part of the cost. It replaces the Colonial Geological Survey. A 12-channel S.I.E. seismograph is in use and a 24-channel seismograph is on order. A Worden gravity meter is in use, and a Worldwide meter is on order. Electrical and electromagnetic methods are also in use. Magnetometers include a portable fluxgate type, which can be used without a tripod for large anomalies; for best results a tripod should be used however.

(See also section on gravity)

Royal Aircraft Establishment, Farnborough - Computing (Mr. Treweek).

The trace-reader which we were interested in about 2 years ago has been further developed by Southern Instruments but not by RAE. It is still only 6 in. wide, but introduces scale-factors etc. The cost is believed to be about £1200.

He doubts whether digital recording would be worthwhile for magnetic observatories normally, because of complication of equipment, lack of reliability, and comparatively small amount of data. However it could be worthwhile for rapid-run recorders.

They have developed an optical digital galvanometer whose sensitive elements are silicon plates about .06 x .03 in., soldered together. The resolution required for their purposes is not very high. If a servo-mechanism is available, e.g. a spot-follower, then a digitised coding disc can be attached to the shaft of the servo-drive. He believes cards or perforated tape are satisfactory for fairly slow data collectors; magnetic tape is usual for very fast collectors.

They have 2 Deuce computers, and a Ferranti Mercury has just been installed. This has much easier programming.

Lamont Geological Observatory, Columbia University. Oceanographic survey vessel "Vema", has a speed of 9 knots and a length of 200 ft.

Gravity observations are made with a Graf sea gravity meter on a stabilised platform. This could be operated about 15% of the time on the last long cruise (see gravity section).

Magnetic recordings are made by both fluxgate and proton magnetometers. The latter is not yet very reliable. Both are towed in a "fish" about 4 ft long, and 1 ft diameter.

Also on board are echo sounders, a winch and corer for bottom (mud) samples to a depth of 35,000 ft (with payout speed of 1000 ft/min), and equipment for collecting water samples for C_{14} measurements (tested back in laboratory). Salinity is measured by resistivity and depth-thermographs, biological sampling equipment, and bottom cameras with light sources are used.

Seismic work requires co-operation of another vessel for best results. This should be capable of carrying approximately 30 tons, including explosives, accommodation for 3-4 scientists (2 from "Vema", which will take 1 or 2 others if available). It should be capable of staying at sea 3-4 weeks, and working 24 hrs/day. Any explosives may be used in charges of $\frac{1}{2}$ lb. and upwards to 300-lb. depth charges. Units used are approximately $\frac{1}{2}$, 3, 10, 25, 50, 150, and 300 lb. New detonators must be supplied. Each profile extends about 60 miles. Information about explosives regulations in ports, facilities for taking on more explosives refuelling etc. is useful. They can install gear on a boat in about 24 hrs., full time, anyway say 4 days, with little local help. They would be interested in a survey of up to 2 months duration, depending on other commitments. Their main interest is in deep sea work.

10. RECOMMENDATIONS

AUTOMATIC COMPUTING METHODS

There is considerable scope for introduction of these techniques into our work.

Plans are being made already for use of automatic computers in the following procedures, which form part of our normal programme and which have been done by hand methods previously :-

Adjustment of loop closures and reduction of total-field (airborne) magnetic survey data

Routine processing of magnetic observatory data

Other procedures which are carried out continuously as part of our normal programme and to which automatic computing techniques have been applied with advantage by other organisations include the following :-

Routine reduction of gravity field data

Recalculation of gravity data for comprehensive maps

Preparation of magnetic charts

Determination of ionospheric median values (at present done by I.P.S. on our behalf)

Procedures which we have occasionally used, but have not done so nearly enough because of lack of staff and the long time involved, include the following :-

Calculation of gravity terrain corrections

Calculation of isostatic corrections

Calculation of gravity and magnetic derivative and residual maps

Calculation of gravity type-anomalies (i.e. anomalies associated with simple geometrical sub-surface features)

Calculation of gravity anomalies associated with irregular two-dimensional and three-dimensional features

Upward and downward continuation of magnetic and gravity data

Procedures which, as far as I am aware, have been carried out only rarely or not at all by the Bureau, but which could make substantial improvements in our interpretations and analysis of data, include the following :-

Calculation of aeromagnetic type-anomalies

Calculation of resistivity multi-layer anomalies

Upward and downward continuation of magnetic and gravity data

Harmonic analysis, e.g. of magnetic observatory data

Further procedures which are related to our work, but which involve some addition to the programme or purchase and use of new types of equipment, are listed below. Most of these additions have been considered at one time or another, and in some cases steps are being taken to put them into effect.

Analysis of tidal gravity data

Determination of earthquake epicentres

Calculation of geoid elevations and deflections of the vertical, from gravity data

Calculation of synthetic seismograms from continuous velocity logs

Interpretation of seismic model studies

Investigation of phase velocity of dispersed seismic waves, with a view to distinguishing artificial explosions from natural earthquakes and studying movement at the source

This summary makes it clear that the introduction of automatic computing should not be designed to reduce staff, but rather to increase the work done on our results. The experience of most organisations is that once a machine is acquired, uses develop for it beyond those originally envisaged and it is soon used to capacity.

I recommend that the Bureau should adopt a policy of hiring time on computing machines for a start. This would enable us to feel our way in two directions; firstly to gain experience with difference types of machine, with a view to deciding on the characteristics we would require; secondly to assess how much machine time we could use on various projects, thus enabling a decision on whether it would be worth buying or renting a machine of given capacity, whether we should share with other Departments, or whether we could use available capacity on an existing machine for all our requirements. This decision I think is difficult until we actually develop automatic techniques for handling much of the data.

The small machines such as IBM1620 certainly sound an attractive proposition for an organisation such as ourselves. This machine is described in Nov.-Dec., 1959 issue of "Datamation" (pages 7-9) and compared with 3 other similar machines, on the whole favourably. If a decision is made to rent or purchase a machine, adequate staff should be available for programming, operation, and maintenance (the latter may be done under contract). About 3 geophysicists or mathemeticians and supporting technicians or computers would probably be required.

For geophysical problems involving a lot of data handling and fairly simple calculations, the ratio of input speed to calculating speed may be important. The cost of a machine is roughly proportional to its calculating speed. Thus for two machines with the same input speed, the one with the slower calculation speed would be more economical for such problems, as the cost of input time would be less (similarly for output time).

New machines are always coming on the market, the old ones soon become obsolete or obsolescent. Naturally a computer in several years (subject to maintenance etc.) is still as good as when it was first bought; it only suffers by comparison with newer models. The chief point about this is that to make the best use of one's money, one should probably buy the most recently developed machine satisfying the requirements. In any case a comprehensive study of available machines should be made before one is selected.

GRAVITY

I recommend that we should proceed with the purchase of the Japanese pendulum equipment, as the performance of this was considered satisfactory by members of the International Gravity Commission. The only other equipment available that I know of is the Askania, although it is possible that the Italian Geodetic Commission may be prepared to make further models of their recently developed equipment.

Morelli recommends that someone should travel to Japan for familiarisation with the equipment and a tie should be carried out Kyoto-Melbourne-Kyoto-Melbourne. The I.G.C. recommends a pendulum tie to be carried out between Melbourne, Christchurch, Buenos Aires, and Mowbray and we should give consideration to using the equipment for this.

In establishing a national gravity calibration chain or network, it is recommended that pendulums should be used to establish stations at about 300-500 mgal intervals and gravity meters for interpolation between these.

TIDAL GRAVITY

Apart from determining the general global tidal constants, the objectives of these measurements is not altogether clear. It is generally agreed that some variation may occur with regional geology, but apart from one or two local studies this has not been investigated very far. With good instrumentation, recording periods of one or two months at a site may be adequate; preliminary tests show that our North American meter has enough sensitivity if the various sources of noise and interference can be controlled.

Horizontal pendulums are a desirable addition, at least at one main station; however, the siting requirements are much more stringent and they are more susceptible to extraneous influences.

MAGNETIC INSTRUMENTS

It is recommended that at least one proton precession magnetometer be obtained for observatory use. This should give a reliable absolute value for total force, and as we believe that our H standards are now reasonably accurate, values could also be obtained for Z and I. Developments in the Rubidium Vapour Magnetometer should be watched with interest.

A room with large Helmholtz coils for simulating any field would be very useful for testing and calibrating instruments. The proton precession magnetometer could be used to determine the coil constants.

Many of the palaeomagnetometers which I saw there were very much simpler than the ANU model, and precautions taken were far less elaborate. While I did not investigate these in any detail, if we ever decide to go ahead with construction of such equipment, it might be investigated whether results of sufficient accuracy for our purposes could be obtained with comparatively simple equipment.

Discussions at Utrecht, together with an examination of some of the magnetic effects (bays, impulses, etc.), reported from our observatories, have made me wonder whether our AIGA reports (or perhaps the checking lists) from all observatories should be checked by one officer, to ensure uniformity within our own organisation. This might particularly apply to Antarctic observatories where the observers change every year.

SEISMOLOGY

The main trends are towards study of longer-period waves and more accurate timing. For study of surface waves, our main observatories should be equipped with one long-period seismograph - the Benioffs with LP galvanometers are not considered adequate.

There is of course plenty of scope in Australia for field refraction studies of crustal structure. If staff can be made available for this in the future, the instrumentation and techniques of Wisconsin University would be worth investigating as a pattern for our activities.

OCEANOGRAPHIC GEOPHYSICS

In view of Australia's geographical situation, there is plenty of scope for geophysical work in the surrounding oceans. Satisfactory techniques have been developed for seismic and magnetic observations from surface vessels, and gravity observations are possible under favourable conditions. Of the two operating seaborne gravity meters, more users favoured the La Coste-Romberg than the Graf-Askania.

Our participation in this field depends on availability of staff and vessel, apart from purchase of equipment. This would not be possible at present unless additional staff could be made available or our programme reduced in some other way. If staff could be provided, co-operation with the naval - C.S.I.R.O. research vessels should be considered.

AIRBORNE GRAVITY METER

It is claimed that useful results can be obtained, but radio navigation aids are essential. At present, traverses must be flown at great heights and so anomalies are representative of large areas. This may be an economical way of getting regional coverage of difficult areas and perhaps of oceans. Work would presumably best be done by contract.

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(ii) Journal of Geomagnetism and Geoelectricity, Vol.X, No.4 (Special Number for symposium on pulsations and rapid variations held at Tokyo, April 1959).

(iii) Coulomb, J. (Paris), "Les Theories des Pulsations".

(iv) J. Oriol Cardús, S.J. PSC Bahias & Pulsaciones (Publicasiones del Observatorio del Ebro, Miscelanea - No.18).

(v) Jacobs, J.A. & K. Sinno, Morphology of Geomagnetic Micropulsations, Pc. (Geophysics Research Division of Air Force Cambridge Research Centre, Contract No.AF19 (604) - 4068).

(vi) M. Okhatsimskaya, Y.Y. Rastrusin, I. Ratitjansky, R. Tchepetnov. Laws of excitation of short-period oscillations in middle lats.

(vii) V. Kebuladze, Sur quelques regularités du champ perturbé des courants telluriques.

(viii) O.V. Bolshakova, K. Yu. Zykin and N.F. Halseva. Some laws in the behaviour of the vertical component of short period oscillations of the geomagnetic field of the stable regime (Pc).

(ix) V. Troitskaya, Continuous pulsations (pc) and pulsation trains (pt) in the Arctic and in the Antarctic.

(x) A.G. Kalashnikov, K. Yu. Zykin, Some results of observing the variation vector of the horizontal component of the geomagnetic field.

(xi) A.G. Kalashnikov, E.N. Mokhova. On the small-period electromagnetic field disturbances appearing simultaneously on large areas.

(xii) V.I. Afanasieva. Short-period oscillations of geomagnetic field.

(xiii) A.P. Nikolsky. On the problem of diurnal distribution of irregular magnetic disturbances in high latitudes.

(xiv) J. Veldkamp. On the current system of solar-flare effects.

(xv) Prof. Kalashnikov. Concerning the agenda of the symposium.

(xvi) Mrs. Troitskaya. Concerning the agenda of the symposium.

(xvii) Jan Bouska. Report on research in pulsations of the electromagnetic field of the earth.

(xviii) J. Veldkamp. Giant pulsations of July 17th 1958.

(xix) Michel Beccaria Étude de la répartition des trains de pulsations (pt) enregistrées à Tamanrasset du 1er Avril 1958 au 31 Mars 1959 suivant la polarisation de leur début.

(xx) A.H. de Voogt, Enregistrement Direct des Vecteurs de Courant Tellurique (Administration Nederlandaise des PTT).

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(xxv) G. Korobkova, N. Nikitina, E. Zubareva, and V. Troitskaya. Giant pulsations in the Soviet Arctic. (For the period 1935-1956).

(xxvi) V.G. Dubrobskiy. The rapid geoelectric and geomagnetic variations and their regularities according to the observations in Ashkhabad.

(xxvii) S. Chapman and S. Akasofu. The theory of sudden commencements.

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(a) National Reports

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(ii) Rapport sur l'activité gravimétrique en Autriche.

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(iv) Gravity Measurements in Canada (by M.J.S. Innes).

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(xiii) Netherlands, Report of grav. activities.

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(xvi) Pologne, Rapport " " " en.

(xvii) Nouveau Réseau Gravimétrique Fondamental de la Pologne.

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(xxviii) Stockholm (Sweden), The fundamental gravity station. (Prof. Brar Wideland).

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(ii) Absolute and First Order World Net, (Special Study Group No.5) (C. Morelli).

(iii) Tying of Gravity Base Station Helsinki to Potsdam and to the European Calibration Line (by Tuano Honkasalo).

(iv) Technique of Measuring Relative Gravity Values by means of Pendulums, Draft Memorandum (B.C. Browne).

(v) Technique des Mesures Effectuées avec les Gravimètres (Jean Martin).

(vi) Calibration of Gravimeters (by Tauno Honkasalo).

(vii) Revisione Critica Delli Misure Effettuate con Gravimetri Worden, dal 1951 al 1959. (C. Gantar and C. Morelli).

(viii) Methodical study of the measurements by pendulum and by gravimeters on the European gravity calibration lines (by K. Marzahn, Munich).

(ix) Die europaischen Gravimetereichlinien (M. Kneissl).

(x) Measurements with Worden Gravimeters carried out in 1958/59 on the European Calibration Line by the Osservatorio Geofisico Sperimentale of Trieste (E. Gantar and C. Morelli) - in Italian).

(xi) Comparison between the values observed by Oservatorio Geofisico Sperimentale - Trieste and those by other observers. (C. Gantar and C. Morelli).

(xii) Collegamenti Gravimetrici Sulla Linea di Taratura Europea e fra le Stazioni di Appoggio ai Collegamenti Intercontinentali con Gravimetri a Piccolo Campo (C. Gantar and C. Morelli).

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(xiv) North American Gravity calibration system, Progress Report on (D. A. Rice).

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(xvii) Méthode Hypsographique de la Rédaction de la Carte Gravimétrique des Anomalies de Faye Dans les Terrains Montagneux (T. Chojnicki).

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(viii) W.M. Kaula, Accuracy of Gravimetrically Computed Deflections of Vertical (Transac., Am. Geoph. Un., Vol.38 No.3.)

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(x) W.M. Kaula, Reconciliation of Stokes Function & Astro-Geodetic Geoid Determinations (Jour. Geoph. Research Vol.64, 1).

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(xv) I. Fischer, A Map of Geoidal Contours in North America (Army Map Service, 1954).

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(xvii) U.A.K. Uotila, Investigations on Gravity Field and Shape of Earth (Ohio State Uni. 1959).

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(ii) G.P. Woollard, Results for a Gravity control Network at Airports in the U.S. (Geophys. Vol. xxiii, No.3, July 1958).

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(vi) S. Hammer & E.T. Heck, A Gravity profile across the Central Appalachians, Buckhannon, W. Virginia, to Swift Run Gap, Virginia. (Trans. Am. Geo. Un., 1941).

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3(e) <u>GENERAL</u>

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4. <u>TIDAL GRAVITY</u>

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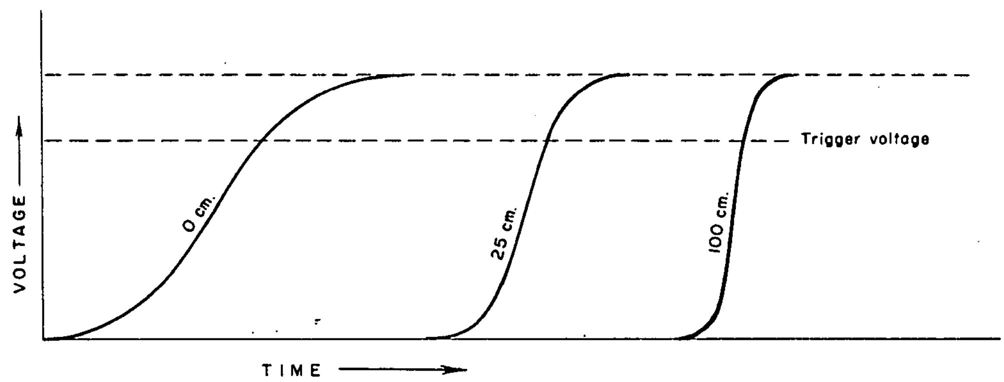


Fig. 1. Output of PE cell for various positions of falling rod.

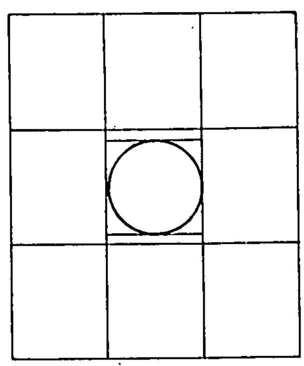


Fig. 2. Central Squares for isostatic calculations.

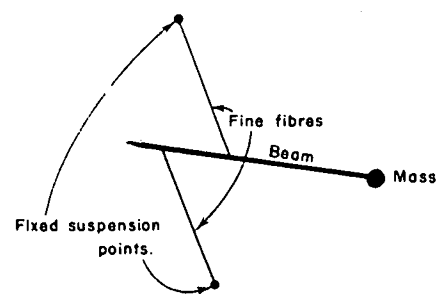


Fig. 3. Scheme of Zöllner pendulums.

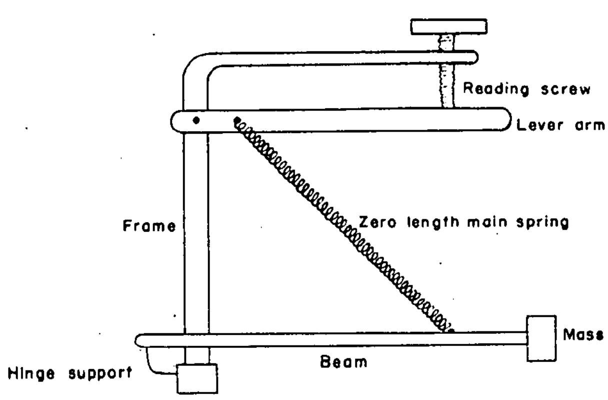


Fig. 4. Sketch of La Coste – Romberg Gravimeter

To Accompany Records 1960, No. 100

Dooley, Overseas Visit, 1959.

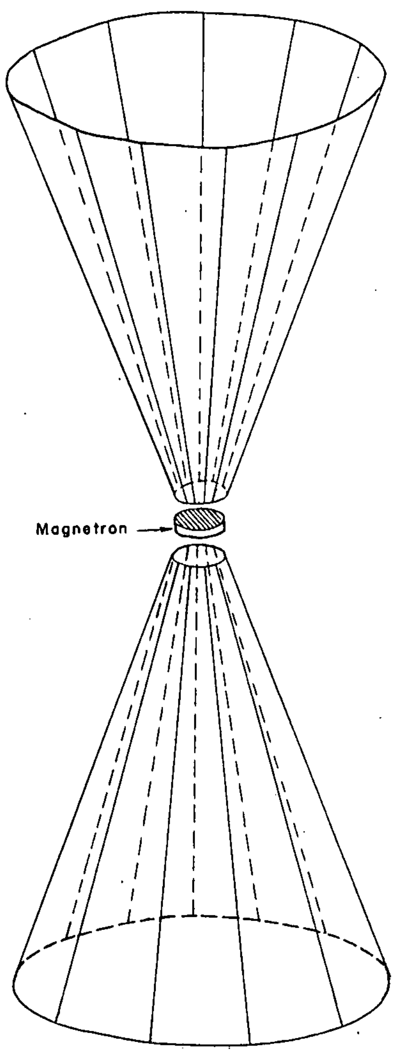


Fig. 5. Magnetron Variometer.

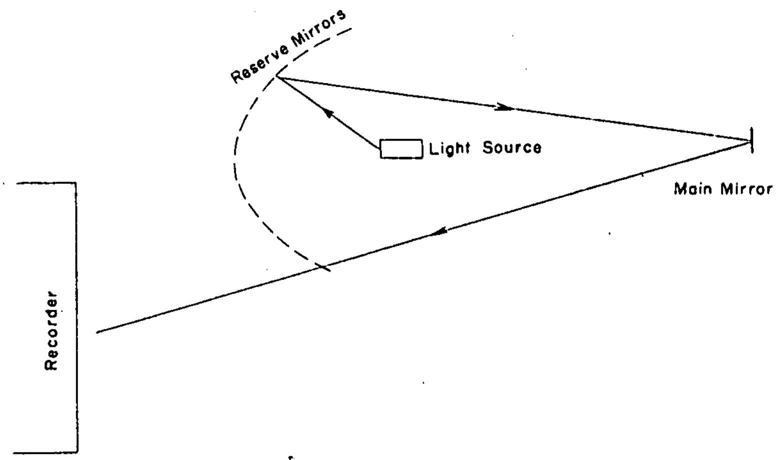


Fig. 6. Optical System, Ruska rapid-run variometer

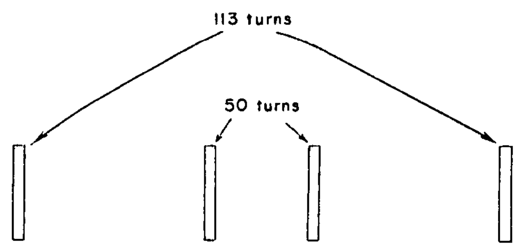


Fig. 7. Approximate arrangement of coils for proton magnetometer, Ottawa.

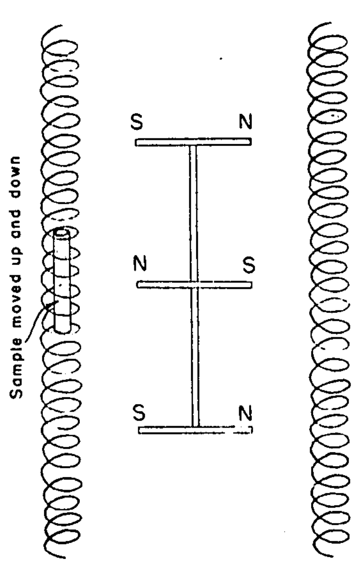


Fig. 8. 3-Magnet astatic system.

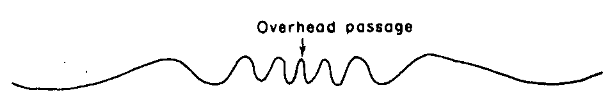


Fig. 9. Record of radio interferometer

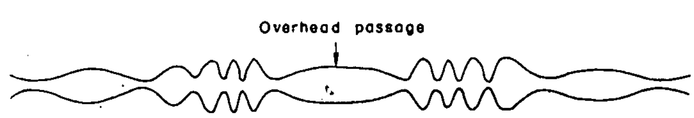


Fig. 10. Fading pattern from overhead transmitter.

Dooley, Overseas Visit, 1959.

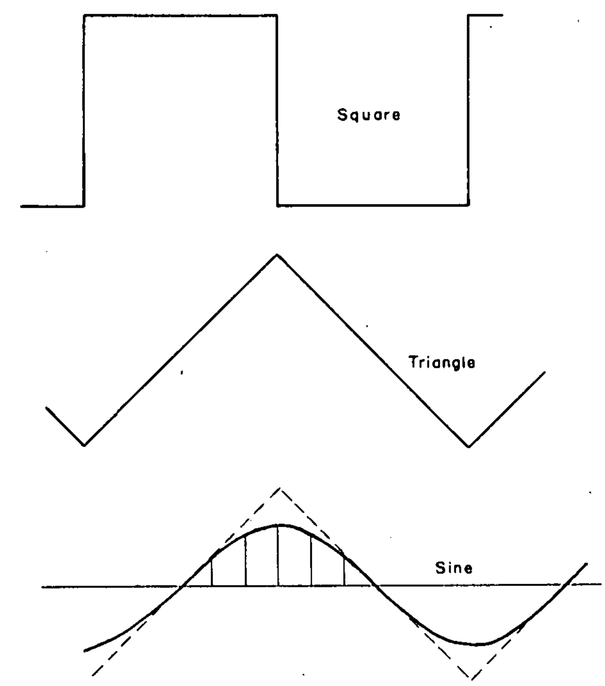


Fig. 11. Slow Oscillator Waves.

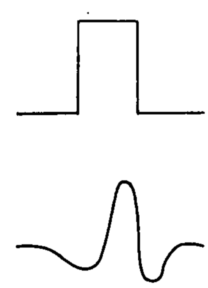


Fig. 12. Pulses for Synthetic Seismograms

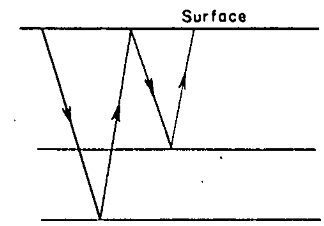


Fig. 13. Second order reflection.

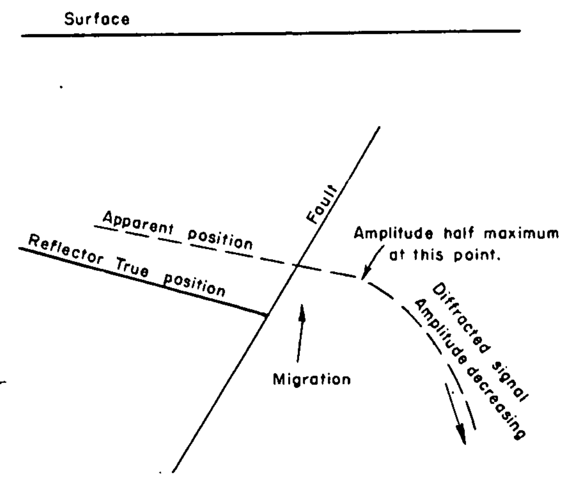


Fig. 14. Diffraction at faults.

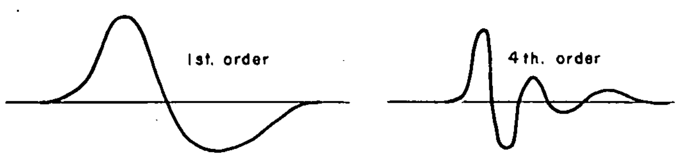


Fig. 15. Laguerre functions.

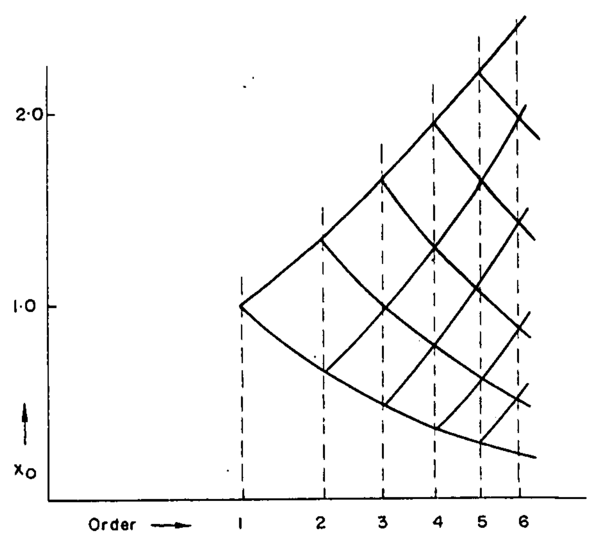


Fig. 16. Zeroes of Laguerre functions.

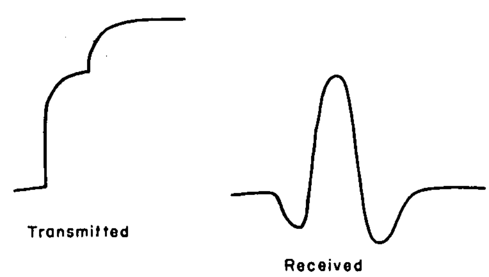


Fig. 17. Pulses in model studies.

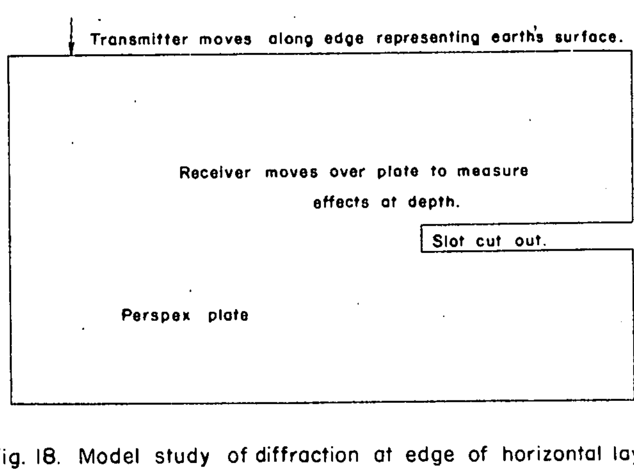


Fig. 18. Model study of diffraction at edge of horizontal layer.

Dooley, Overseas Visit, 1959.

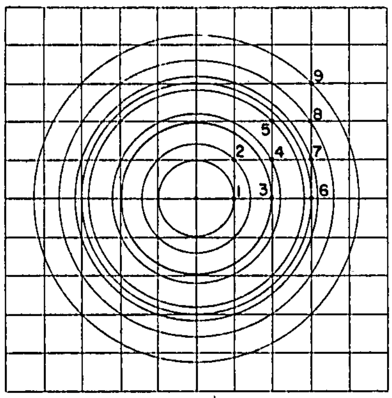


Fig. 19. Rings for Regional Polynomials.

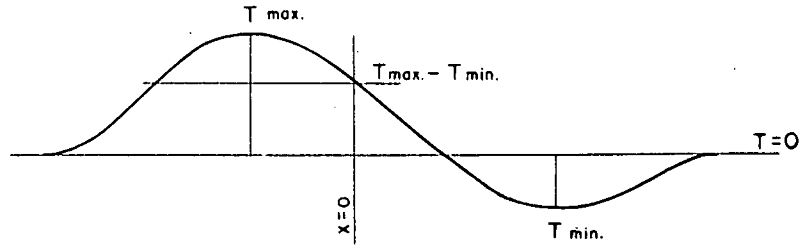


Fig. 20. Calculation of pseudo-gravimetric anomalies.

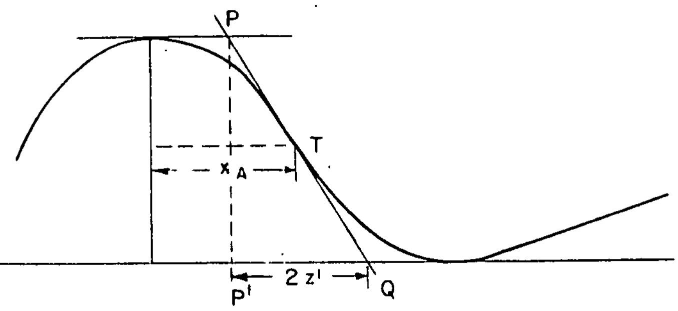
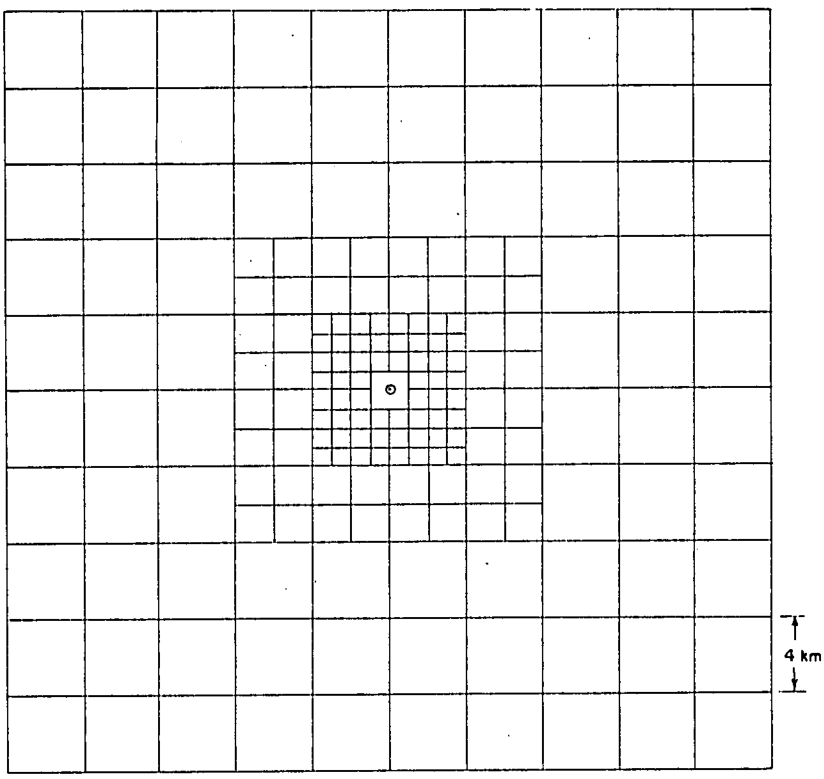
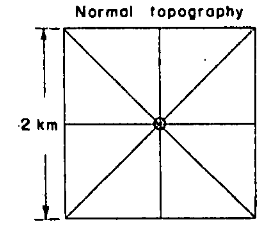


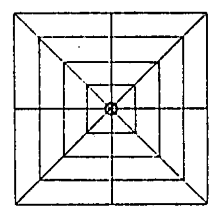
Fig. 21. Interpretation of pseudo-gravimetric anomalies.



Normal topography



Subdivision of central square.



Rough topography

Profile along wedge

Fig. 22. Square chart for terrain corrections.

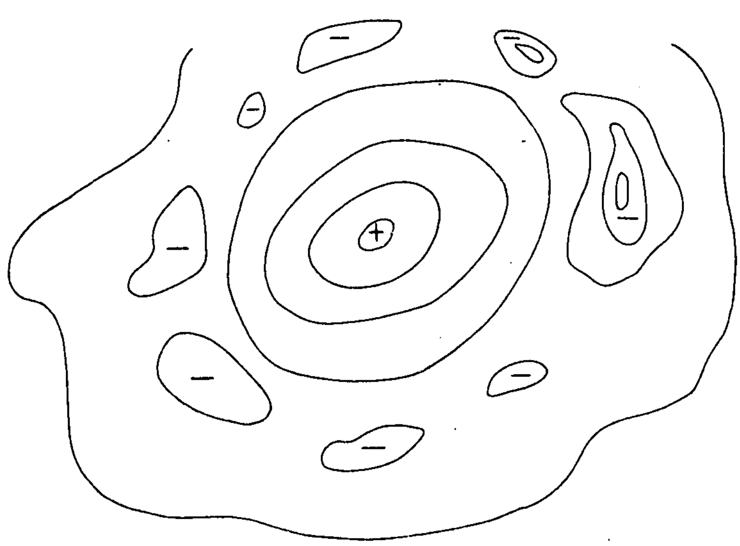


Fig. 23. Circular zone of negative magnetic anomalies.

Dooley, Overseas Visit, 1959.