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OBITUARY

Dr. George WOOLLARD
(1908 - 1979)

Dr. George WOOLLARD, an internationally known geophysicist whose gravitational studies were instrumental in helping scientists redraw the shape of the Earth, died of a heart attack Sunday 8 April at Queen's Medical Center. He was 70.

Regarded by his colleagues as one of the top six geophysicists in the world, he was perhaps known as much for his compassion and personal warmth as for his scientific work .

Orphaned in early childhood, Dr. WOOLLARD took great interest in the plight of orphans, and five of his nine children were adopted.

Upon graduation, he went to Princeton, where he obtained a doctorate in geophysics in 1937.

During World War II, WOOLLARD worked on underwater sound at Woods Hole Oceanographic Institute and then went to the University of Wisconsin, where he worked from 1948 to 1962. He became director of the Polar Research Institute in Wisconsin, an organization he created.

Dr. WOOLLARD served as director of the University of Hawaii's Institute of Geophysics from 1962 until his retirement in 1974.

In 1939 Dr. WOOLLARD was one of the first geophysicists to take his instruments out of the laboratory and into the field.

His greatest contribution was in the areas of standardization of gravity observations throughout the world and of geological interpretation of the gravitational field through interdisciplinary geophysical studies.

His work helped prove the theory that the Earth is not a sphere, as had long been believed, but is in fact somewhat flattened at the poles with a wide range in local gravitational force .

More recently, his work helped others in predicting variations in the orbits of satellites due to this unequal gravitational distribution.

Dr. WOOLLARD was past president of the American Geophysical Union and a former member of the executive council of Geological Society of America and the board of the American Geological Institute. He also served on various committees of the National Academy of Science, the National Aeronautical and Space Administration, Advance Research Projects Agency, the State of Hawaii and the International Union of Geodesy and Geophysics.

In 1973 the American Geophysical Union presented him with the William Bowie Medal for his outstanding contributions in fundamental geophysics, calling him "a man of huge and cheerful vitality, with an infectiously lively and critical interest in every aspect of geophysics".

Scientists from all over the world came to Hawaii in 1974 to honor him at an "International Woollard Symposium".

He attended at many times the meetings of the International Gravity Commission in Paris and the International Gravity Bureau will miss a friendly and efficient Correspondent.

From : Honolulu Advertiser, April 10, 79.
Star, Bulletin, April 9, 79.

REPORT OF THE MEETING OF INTERNATIONAL GRAVITY BUREAU (IGB) WORKING GROUP NO. 2 (WG2)

"WORLD GRAVITY STANDARDS"

11, 12, 14 SEPTEMBER 1978
PARIS, FRANCE

ATTENDEES

U. Uotila, Convenor
R.K. McConnell, member
B. Szabo, member
W. Torge, member
L. Wilcox, member
S. Coron, Ex-officio member
J.J. Levallois, Ex-officio member
J. Lepetre, guest
I. Marson, guest
W. Strange, guest
J. Tanner, guest
C. Whalen, guest
O. Williams, guest

The report of WG2 meeting held 21-25 February 1977 was approved as published in IGB Bulletin d'Information No. 40, May 1977.

Mr. McConnell distributed "Report to World Gravity Standards Working Group on the Status of IGSN71 Stations". Of the 1853 IGSN71 stations, a total of 1398 are considered still to be active although it should be noted that all stations whose status is not known are included in the active file. The remaining 455 stations are deleted, destroyed, obsolete, or restricted. The total number of IGSN71 stations is now considered to be 1853 rather than 1854 because it was discovered that two stations in Brisbane are virtually identical. The largest number of stations (405) for which updated status information has not been received is in the United States. The needed information will be provided by W. Strange. All available updated IGSN71 station description sheets have been deposited at the IGB. A current tape of IGSN71 gravity values also have been furnished to the IGB.

Mr. McConnell reported receipt of information pertaining to new base ties within several European countries. Similar data also have been received from Australia and South America. Japan has completed a new national gravity base network.

Dr. Uotila pointed out that all IGSN71 stations are still active in the sense that all stations can be used in future adjustments where ties exist through them. The destroyed, obsolete, etc. stations are inactive only in the sense that they cannot be reoccupied to establish new ties.

Mr. McConnell distributed "Report to World Gravity Standards Working Group on the Adjustment of the Latin American Gravity Standardization Net 1977 (LAGSN77). The LAGSN project was initiated by the SILAG working group of the Pan American Institute of Geography and History (PAIGH) in 1973. Observational data needed for the adjustment was obtained using about 14 Lacoste-Romberg gravimeters furnished by the Inter American Geodetic Survey (IAGS). The ties were made by IAGS or Latin American personnel. Roman Geller of IAGS was instrumental in data acquisition and survey coordination throughout the project. All national nets were connected to IGSN71 stations, and some national nets were interconnected. Uruguay is only tied weakly to Buenos Aires, and the gravimeter used in Uruguay was not used elsewhere. All IGSN71 stations were weighted more or less inversely proportional to their standard error and included in the adjustment. The data from the Brazilian national net was not included in the LAGSN77 due to unresolved problems, but will be added later. During its August 1977 meeting, the PAIGH passed a resolution to adopt the LAGSN77 as a reference standard for South America. Mr. McConnell noted that Canada would like to transfer the LAGSN77 data base and its maintenance to a Latin American country. Although Chile, Peru, Venezuela, and Brazil all have expressed interest in taking over management and maintenance of the LAGSN77, none appear to be financially able to do so at present. Outside funding support is needed to get the project going in Latin America.

The Working Group members agreed that the Canadian Earth Physics Branch (EPB) should be commended for doing an excellent job with the LAGSN77 project. It was agreed that a resolution be formulated for consideration by the International Gravity Commission (IGB) recommending that the LAGSN77 be adopted as a provisional absolute gravity standard for Latin America. The text of this resolution, as approved by the IGC on 15 September 1978, is as follows:
(Resolution N° 2)

The International Gravity Commission:

Considering that national gravity networks have been observed to modern standards in most countries of Latin America through co-operation of national agencies with the Inter-American Geodetic Survey and, considering that a unified adjustment of these networks carried out by the Earth Physics Branch, Ottawa has been reviewed and endorsed by the World Gravity Standards Working Group.

Recommends that the system known as the Latin American Gravity Standardization Net 1977 (LAGSN77) be used as a provisional absolute reference standard for Latin America and further recommends that:

(1) additional measurements be carried out to strengthen the ties between national networks

(2) that the LAGSN77 be extended to include Brazil at the earliest possible opportunity

(3) that a program be established to provide for on-going maintenance and extension of LAGSN77.

The Working Group agreed to recommend that a report on the LAGSN77 be published * in the IGB Bulletin d'Information, and to recommend that all scientists working on gravity base net adjustments be encouraged to keep the IGB Working Group No. 2 informed on the progress and results of such activity.

The Working Group agreed that standard procedures for observing base networks and documenting station locations and results of the work be written and published in the IGB Bulletin d'Information. The purpose of this is to provide a guide to all scientists who are planning a national gravity base network. Mr. McConnell was requested to prepare a manuscript for circulation among WG2 members. Publications will be effected by WG2. Whalen noted that the U.S. National Geodetic Survey (NGS) has published observing procedures for horizontal and vertical control in the U.S. A similar document for gravity surveys is in the planning stage. Mr. Whalen will provide a copy of the NGS documents to Mr. McConnell.

The Working Group agreed to recommend exclusive use of Lacoste-Romberg gravity meters for all base network observations. The use of other, older types of gravimeters is not recommended for this purpose.

Mr. Levallois gave a report on the IGB project to adjust the second order gravity base nets in Africa to the IGSN 71 datum. The gravity base nets in Africa are scattered and often not linked together. Frequently the only usable ties are to IGSN71 stations. Some of the nets are very old, and much of the material is not very homogenious with respect to density and distribution of stations, accuracy of measurements, and availability of station descriptions. Because of these and other problems, no general adjustment of the African nets is possible. Rather, each net has been adjusted to the IGSN71 datum separately in the best manner possible. In some places, scale has not been established due to single point ties to IGSN71. The accuracy of these adjustments ranges from 0.15 mgal to 1 mgal or worse. The IGB has published the results of the first year's work. More results will be published next year. The work is being supported by UNESCO.

* in the next Bulletin d'Information, November 1979.

Dr. Uotila requested Mr. Levallois to submit recommendations to WG2 on what actions should be taken to improve the African gravity base network. The recommendations should include any actions necessary to improve the IGSN71 in Africa.

Dr. Uotila suggested that WG2 recommend procedures to be used in establishing new gravity nets such that older existing work can be tied in better, thereby improving the utility of older nets.

The group agreed that two essential ingredients in establishing any new base network are:

a. Calibrate gravimeters over a gravity range twice as large as that to be encountered in the area to be surveyed, and

b. Establish ties across all borders to adjacent countries.

Mr. Marson reported on differences between new absolute measurements using the Italian apparatus and IGSN71 values along the European calibration line. Agreement between the absolute measurements and IGSN71 values is about 0.05 mgal at 13 stations. Larger differences were found at two stations: 0.1 mgal at Hamburg and 0.08 mgal at Torino. The problem at Hamburg has been resolved in favor of the absolute value by new relative ties made by the Germans since IGSN71 was completed. The problem at Torino is not known but may be related to local ground stability problems.

Mr. Szabo reported on absolute measurements in the United States. The Italian absolute apparatus was used to measure six sites in the U.S.: Bedford, Denver, Bismarck, San Francisco, Almagardo, and Miami. These sites were selected by a statistical analysis of the U.S. portion of the IGSN71 net designed to indicate where new absolute measurements are most likely to improve the system. The absolute measurements at the six sites agreed very well with IGSN71 values. In March-June 1978, Mr. Hammond used his absolute appartus to measure gravity at four of the six sites previously occupied by the Italian instrument: San Francisco, Bedford, Denver, and Almagardo. The Italian and Mr. Hammond's measurements agreed to 15-20 μgal at San Francisco, but there was a 50-80 μgal systematic discrepancy at the other three sites. The cause of the discrepancy is considered to be a problem in Mr. Hammond's instrument. Mr. Hammond's first priority is to find and correct the instrumental problem which is causing the systematic discrepancy. His second priority is to make additional measurements in the U.S. to further analyze the IGSN71 net in the United States. Stations to be occupied will be selected in cooperation with the U.S. Gravity Base Coordinating Committee. When this work has been completed, consideration can be given to making measurements outside of the U.S.

The Working Group agreed that additional intercomparisons between measurements made by different absolute equipment is to be encouraged.

In light of the reports given by Mr. Marson and Mr. Szabo, the Working Group notes with pleasure that IGSN71 values in Europe and the U.S. show an excellent overall agreement with the new absolute measurements.

Dr. Uotila raised the question of whether or not the Honkasalo correction should be applied to measurements used in gravity base networks. Application of this correction computationally removes the sun and moon to infinity, and this causes the geoid to depart slightly (about 15cm) from the mean sea surface at the equator and poles. Since this is a rather controversal issue involving geoid interpretation, WG2 agreed that the matter should be referred to Sections IV and V of the International Association of Geodesy (IAG) for decision. Dr. Uotila will correspond with the Presidents of IAG Sections IV and V and request that the matter be resolved at the next assembly of the IAG in Canberra next year. WG2 agrees that there must be a uniform way of handling the Honkasalo correction problem--but that the decision should not be made by the IGC or IAG Section III. It was noted that the Honkasalo correction was applied to measurements used in the IGSN71 adjustment. If the IAG decides not to use the Honkasalo correction, the IGSN71 can be recomputed to remove the effects of the correction.

The group discussed the advisability of recommending a standard formulation for tidal correction application to gravity measurements. Mr. Torge was requested to develop a recommendation for the formula to be used for tidal and Honkasalo corrections. When the question of what to do with the Honkasalo correction is resolved, Mr. Torge's recommendations will be used to develop a resolution for consideration by the IGC. The text of this resolution, as adopted by IGC on 15 September 1978 is as follows:

See Resolution N° 1, p.I-10.

Mr. Strange suggested that a policy for dealing with ocean tidal attraction and ocean loading. Mr. McConnell pointed out that ocean loading can amount to 100 μgal near some coastlines. Dr. Uotila suggested that resolution of this problem be postponed until the oceanographers develop appropriate tidal models and instructions for their use. In the meantime, it appears best to avoid coastal areas when establishing stations for gravity base nets. Mr. Strange noted that, given current microgal accuracies of absolute measurements, it will be necessary in the future to consider rainfall, water table, and other seasonal variations which may affect gravity.

Mr. McConnell and Mr. Marson proposed that a number of Lacoste-Romberg gravimeters be recalibrated using the new absolute measurements made with the Italian appratus. The new absolute measurements to be used generally run along but do not always coincide with stations included in the European Calibration Line (ECL) from Hammerfest to Catania. The main purpose of the recalibration is to detect any non-linearities (second or higher order terms) in gravimeter performance. Although there does not appear to be a non-linearity problem when the mean of several meters is used, individual meters sometimes gives systematic discrepancies of up to 150 μgal when compared to the mean. Such discrepancies, which occur more frequently in instruments manufactured prior to 1970, may be due to non-linearities in meter performance. WG2 agreed to accept this proposal, and also requested that Mr. Hammond's apparatus be used to repeat absolute measurements at a number of sites previously occupied by the Italian apparatus along the ECL. Mr. Szabo indicated that this recommendation will be taken into consideration. Mr. McConnell was requested to formulate an appropriate resolution. The text of this resolution, as adopted by the IGC on 15 September 1978, is as follows:

See Resolution N° 3, p.I-10.

Mr. Strange requested that future consideration be given to the establishment of new calibration lines based on absolute measurements in Africa and the Americas.

Dr. Torge distributed a proposal for discussion authored by E. Reinhart and G. Boedecker concerning the combination of national gravity measurements. This proposal for discussion relates to a WG2 policy published in IGB Bulletin d'Information No. 40, namely, that the gravity values of IGSN71 stations shall be introduced into national gravity network adjustments as observations with the appropriate elements from the variance-covariance matrix of the IGSN71 adjustment. This policy will not enable the "best" values to be computed for the new German national base network. The new German first order network contains 21 stations. Of these, 11 are identical with or strongly linked to IGSN71 stations. The net is also tied into four absolute measurements made by the Italian apparatus in 1977. The relative ties were made during 1977-78 using four Lacoste-Romberg gravimeters. A network adjustment using only the absolute values and new relative ties was made and the accuracy of the result is 0.01 μgal. When the adjusted values are compared to IGSN71 values at common stations, a systematic scale difference on the order of 1.6×10^{-4} is found. If the WG2 policy of including IGSN71 values in the adjustment is used, this systematic scale error will be built into the new German network and this is clearly undesirable. Mr. Torge also noted that the German network will be reobserved in about 1987 to check for any time changesover the 10-year period. Since the IGSN71 contains observations made as early as 1955, adjustment of the German net to IGSN71 values will make it useless as a basis for detecting time changes over the 10-year period 1977-87.

As a result of Mr. Torge's presentation, WG2 agreed to revise its policy with respect to national network adjustments. WG2 now recommends that new national gravity base networks be tied exclusively to new high accuracy absolute measurements whenever a sufficient number of such measurements exist within the country. The absolute measurements establish the absolute datum and scale for the country. Whenever absolute measurements are not available within a country, weighted IGSN71 values, including covariances, may be used to establish datum and scale. Within these general guidelines, each country is free to decide whether to use absolute measurements and/or weighted IGSN71 values to control datum and scale of new national networks.

Based upon comparisons between IGSN71 values and the new absolute measurements, WG2 agreed that the IGSN 71 will be an adequate global standard for the foreseeable future, and that no future global adjustment is likely to be made. Instead, IGSN71 gradually will be replaced by national networks adjusted to absolute measurements.

However, it is desirable that such national adjustments be made according to WG2 standards and subject to WG2 monitorship.

In order to facilitate completion of future national adjustments, Dr. Tanner and Mr. McConnell will attempt to make the facilities of EPB available to all countries which do not possess facilities of their own. Under this arrangement, representatives of such countries could travel to Canada and perform national base network adjustments according to WG2 standards. Each country would be expected to underwrite all costs of travel, per diem, and the salaries of their own people designated to do the work. The facilities would be provided by EPB at no cost to the visiting country. Averall direction will be provided by EPB, but visiting countries are expected to provide all supervising personnel and underwrite the costs of experts and training, as needed. The EPB proposal was gladly accepted by WG2.

Mr. Levallois indicated that IGB has offered to help any African country adjust their national gravity net to the IGSN71. He announced that the IGB also plans a general adjustment of the first and second order gravity networks in France.

LUMAN WILCOX
Recorder

Resolution N° 1

The International Gravity Commission
considering the high accuracy of measurements with current relative and absolute instrumentation and,
noting the importance of comparing the results obtained by different instruments
recommends that :
1. A uniform model for the theoretical computations of tides be adopted by I.A.G.,
2. Gravimetric tides be observed in the vicinity of absolute measurement sites,
3. New absolute measurement sites be located at sufficient distance from the ocean to reduce the influence of the ocean tides.

Resolution N° 3

The International Gravity Commission
considering the admirable progress in achieving the objectives of I.A.G. Resolution N° 18 from the Grenoble meeting and,
considering that the basis of a new long range gravimetric calibration line is formed by the following sequence of absolute stations : Catania, Roma, Torino, Münich, Wiesbaden, Braunsweig, Hamburg, Copenhagen, Goteborg, Gavle, Vaasa, Sodankyla and Hammerfest,
recommends :
1. That all absolute gravity instruments be intercompared at as many stations as possible on this line,
2. That this line be used to evaluate long period non-linearities in relative gravimeters in order to improve the accuracy of these instruments for transferring absolute scale to other parts of the world.

COMPTE-RENDU VIIIth MEETING of the INTERNATIONAL GRAVITY COMMISSION

Paris, 12-15 Sept. 1978

Item IV - INTERNATIONAL GRAVITY STANDARDIZATION NETWORK

A meeting was held on Wednesday 13 September, at 2.30 p.m. under the Chairmanship of Prof. C. MORELLI.

The Chairman gives a general view of the work carried out and described in the report distributed to all the delegates.

He indicates the new nets and their conversion in IGSN 71 ; particularly, he pays attention to the big work in Latin America.

"Under the auspices of the Pan American Institute of Geography and History (PAIGH) and in cooperation with the Inter-American Geodetic Survey Office in Panama, the Gravity Division of the Earth Physics Branch, EMR Canada has compiled and adjusted a gravity reference network of 1005 stations in Latin America".

At the end of this session, Mr. McCONNELL gives some details on the "Report to World Gravity Standards Working Group on the Adjustment of the Latin American Gravity Standardization Net 1977 (LAGSN 77)".

As it is mentioned in the Compte-Rendu of the W.G. N° 2*, this report will be published in the next Bulletin d'Information (November 1979).

Dr. G. BOEDECKER reports on : "The New Gravity Base Net of the Federal Republic of Germany (DSGN 76), Status Report September 1978".

In the Federal Republic of Germany, a new gravity base net (Schweregrundnetz 1976 der Bundesrepublik Deutschland, DSGN 76) has been established since 1975 on behalf of the German Geodetic Commission by the German Geodetic Research Institute. The paper deals with the arguments for this renewal, the design of the net, performance of the observations as also preliminary results. Attention is directed to the discrepancies ($\sim 1.10^{-4}$ in scale) between IGSN 71 values and absolute gravity measurements carried out with the absolute gravity meter of the Italian Geodetic Commission by the Group of Istituto Metrologia Torino. The net comprises 21 stations with 3 excenters each. 11 of the stations are identical or closely connected with IGSN 71 stations, at 4 stations absolute measurements have been carried out, 44 connections were measured 1977 with 4 LaCoste-Romberg gravity meters repeatedly.

Concerning the discrepancies between IGSN 71 values and absolute gravity measurement, Dr. I. MARSON notes that the new German Gravity Net confirms the discrepancy in Hamburg that we have between absolute Measurements and IGSN 71.

* See green sheets p. I-5-6.

Ing E. KANNGIESER reports on : "Direct Comparison of Absolute and Relative Gravity Measurements in the Federal Republic of Germany and in Northwestern Europe".
(with W. TORGE & H.G. WENZEL)

Relative gravity measurements in the Federal Republic of Germany (FRG) 1978 and in the region of the North-West European Lowland Levelling (NWELL) 1976 give average differences of $\pm$ 8.10^{-8} ms $^{-2}$ between the adjusted gravity values from relative measurements, and the absolute values observed with the transportable apparatus of the Istituto di Metrologia "G. Colonnetti", Torino. So both systems seem to be compatible with the 10.10^{-8} ms^{-2} accuracy level.

Dr. I. MARSON presents the paper : "First Order Gravity Net in Italy". (with C. MORELLI).

He gives the results of the new first order gravity Net, performed in Italy in 1977. Four LaCoste-Romberg model G and one model D meters, 49 base stations and 578 ties have been used. The standard error of the final g value is resulted within the limits 6-22 µGal. The previous national net has been converted in the IGSN 71 system.

Ing. J.J. LEVALLOIS gives some information on the Adjustment of the French Gravimetric Net.

Dr. AARHUR presents the paper : "Adjustment of Precise Gravity Network of Airport Stations in India in the IGSN 71 System". (with K.L. KHOSLA & P.S. BAINS)

A precise gravity network of 42 stations based on the first order gravity station at Pālam Airport, New Delhi was first established in 1971 covering the airports of the whole country in order to provide bases for future gravity surveys in India with a repeatability $\pm$ 0.05 mGal or less.

The observations of this national gravity base network has been adjusted within the framework of the International Gravity Standardization Net 1971 (I.G.S.N. 71).

Separate adjustments have been carried out holding one station fixed and by including two, three or four stations of I.G.S.N. 71 in the adjustment.

The adjustment with one station held fixed gives the most favourable results, the standard error of the estimated gravity value of each station is less than 0.02 mGal. Though this procedure indicates a good internal consistency of the net, there is room for improved scale control.

The procedures and the results of the adjustment have been reported along with plans for future work.

Mr. R.K. McCONNELL indicates that :

"The scale calibration of LCR gravimeters as supplied by the manufacturer is generally too small by 2 to 5 parts in 10^{-4}. Therefore, since you have not included scale unknowns in your adjustment, it would appear that the discrepancies between IGSN 71 and your adjustment are largely due to this fact".

Then, Prof. C. MORELLI points out the big work made by the W.G. N° 2 The Compte-rendu of this W.G. "World Gravity Standards" is presented by Dr. U.A. UOTILA (Convenor) and is reported in the previous pages (see green sheets).

At the end of this session and Friday afternoon Ms V. GODLEY reports on the 2 papers of Dr. G.P. WOOLLARD :

1)"Progress in the Global Standardization of Gravity" and

2)"The new Gravity System : Changes in International Gravity Base values and Anomaly Values".

1) The history of improvements in the global standardization of gravity values since the advent of high range gravimeters in 1948 is reviewed. In particular the gravity base values given in SEG Special publication "International Gravity Measurements (Woollard & Rose, 1963) are evaluated against the most recent set of standardized gravity base values, The International Gravity Standardization Net, 1971 (Morelli et al, 1974). Adjunct IGSN 71 values prepared by the U.S. Defense Mapping Agency Aerospace Center (unpublished) are also used to give a more comprehensive worldwide comparison of values. The results for 787 comparisons of Woollard & Rose (1963) values and IGSN 71 values for the same sites indicate that, in general, there is no difference in gravity standard represented. However, there is a mean absolute datum difference of 14.7 mGal (standard deviation 0.25 mGal)....
...

2) Pendulum interval comparisons and local gravimeter ties to the modern absolute gravity sites at Gaithersburg, Maryland ; Teddington, England ; Sèvres, France and Potsdam, East Germany indicate that the correction of 14 mGals to the Potsdam datum incorporated in the IGSN 71 values is correct to within .03 $\pm$ .016 mGal. Although there appear to be occasional discrepancies in the IGSN 71 values of the order of 0.1 mGal, in general their reliability appears to be better than $\pm$ 0.1 mGal. A discrepancy of approximately - 0.03 mGal per 1000 mGal is indicated, (over the range 4800 mGal).

The difference in anomaly values found, and which is non-linear, ranges from + 2.45 mGal at the equator to - 11/12 mGal, at the poles with zero difference at approximately 25° latitude. Examples are given for the conversion of existing gravity surveys to the new system, and even if the original data are no longer available or only an anomaly map exists that was on a floating datum.

Item III - ABSOLUTE GRAVITY MEASUREMENTS

A meeting was held on Wednesday 13 September, at 10.15 a.m. under the Chairmanship of Dr. A. SAKUMA.

The Chairman summarizes the works made from 1974-78 at Sèvres (B.I.P.M.) and at Mizusawa Observatory.

From 1972, the International Latitude Observatory, Mizusawa, Japan, has in preparation a new absolute station, in cooperation with BIPM. Under construction at BIPM are a Michelson interferometer, in vacuum and on anti-vibratory support ; an Hc-20Ne laser ; and a totalizing chronometer. The other parts are in fabrication in Japan.

It is expected that the assembling and calibration of all the equipment of the Mizusawa station will be concluded in 1978.

Further he gives some details concerning the absolute transportable instruments. Only one instrument, which is a miniturized version of the stationary equipment at BIPM, is presently operating, namely that of the Istituto di Metrologia "G. Colonnetti" in Torino of the italian NRC. However the Society JAEGER (Paris) which is constructing the apparatus of this type has just received an order from Japan.

Prof. U. UOTILA is happy to remark that IGSN 71 values and absolute values agree with stated accuracy of IGSN 71, namely 0,1 mGal.

However, to explain the small differences (particularly at Sèvres) between new absolute "g" values and IGSN 71 system he indicates that the Working Group is just now evaluating use of "Honkasalo correction".

Prof. Yu.D. BOULANGER made a report on "Results of Absolute Measurements in Ledovo, Potsdam and Paris.

He recalls that an absolute ballistic gravimeter of portable type has been constructed at the Institute of Automatics and Electronics of the Siberian Branch of the USSR Academy of Sciences. It was based on observations of non-symmetric incidence of angular reflector in vacuum. The weight of this instrument is about 650 km. The gravimeter can be transported by autocar or by aircraft. The official metrological accuracy is on the order of ± 7-8/µgal. Continuation of the work on the point, assembling and disassembling including is on the order of 4-5 days depending on the conditions of observations.

By this instrument repeated measurements were made in Moscow (Ledovo point), Potsdam, Singapore and Sèvres (Paris).

To extend further the IGSN 71 network four sites of the USSR fundamental gravimetric network were involved in it : Ledovo (Moscow), Murmansk, Nakhodka and Odessa. By means of pendulum OVM instruments and GAG gravimeters a reliable adjustment of the Ledovo site which is within the basis of the USSR gravity network was made with the World Reference Gravimetric Site in Potsdam.

During the recent years a number of measurements with laser IAE gravimeter were carried out. Measurements on the basic gravimetric network of the USSR were controlled, measurements at the Singapore, Potsdam and Sèvres A_3 sites were accomplished. The last measurements allowed to compare the work of three laser gravimeters : a stationary gravimeter by Prof. SAKUMA, Italian instrument and Soviet gravimeter. Maximum discrepancy in the results of measurements by three instruments appeared to be equal to 13 μ Gal while maximum deviation from the mean is 8 μ Gal. As a result of these measurements in Sèvres for the point A_3 a gravity acceleration value was obtained equal to 980 925 930 ± 4 μ Gal. Comparison of this value with that of gravity acceleration given in the catalogue of the IGSN 71 system showed the gravity value at the initial site of the IGSN 71 to be lower by 50 ± 15 μ Gal.

At the question Dr. J.A. HAMMOND, on the absolute accuracy of measurement at Sèvres, the speaker indicates that the absolute accuracy is 12 μGal and the standard error is 2 μGal.

Prof. Yu.D. BOULANGER presents a second report on "Correction to the Potsdam System".

When comparing the Potsdam system with IGSN 71, corrections for scale change were introduced to Δ g values measured in Potsdam system and those of Honkasalo to g values. ...

On the average the Potsdam system correction appeared to be equal to - 14002 ± 15 μGal.

Attention is drawn by the systematic difference of correction values, obtained on european sites and those located on other continents. In the first case the correction appeared to be equal to - 14034 ± 4 μGal, in the second - 13969 ± 18 μGal. It is difficult to explain such an essential discrepancy by a random combination of measurement errors. It is rather a result of irregular distribution of sites, setting the scale of IGSN 71 system.

Mr. B. DUCARME presents a paper "Precise tidal corrections for high precision gravity measurements".

by B. DUCARME, C. POITEVIN & J. LOODTS

For very precise tidal gravity corrections it is necessary to take into account the observed amplitude factors δ & phase differences α for the main diurnal and semi-diurnal components. The global method using a fixed factor δ = 1.16 or δ = 1.20 gives tidal predictions with errors that can reach 50 nm s^{-2} (5 microgals). From the results of the Trans European Tidal Gravity Profiles (1970-1973) isolines have been computed for δ and α in Western Europe. They can insure in continental areas a precision better than one per cent on the predicted tides (errors less than 10 nm s^{-2}). An application has been made on the belgian gravity network.

Dr. C. TSCHERNING makes the following remark :

Regarding figure 2 of the paper (especially Denmark) shows that the Digital Terrain model is not appropriate, because the variation of the signal is not a continuous function. Geologically different zones should be treated differently.

I question the investigation of the precision of the digital te terrain model. The investigation shows only that the function is well represented in areas, when the variation is small.

The Resolution N° 1 (Bull. Inf. N° 43, p.I-25) is recalled :

Recommending that :

1) A uniform model for the theoretical computations of tides be adopted by I.A.G. and,
2) Gravimetric tides be observed in the vicinity of absolute measurement sites ...

On the other hand, the International Center of Earth Tides (ICET) is ready to provide its support to people needing precise gravimetric tidal corrections.

Dr. J.E. FALLER reports on "Progress on the development of a portable absolute gravimeter".

by J.E. FALLER, R.L. RINKER & M.A. ZUMBERGE

See complete text at the end of this item, next page.

Dr. J.A. HAMMOND gives details concerning "The AFGL Absolute Gravity Program".

Dr. I. MARSON presents a paper on "Results of Absolute Gravity Measurements".

Results of absolute gravity measurements in Europe and U.S.A., performed with the italian apparatus, have been presented. Since 1977, 19 absolute gravity stations were instituted in Europe and 6 in the U.S.A. with the transportable apparatus of the Istituto di Metrologia "G. Colonetti". The uncertainty of the measurements is of the order of 10 µGal. An adjustment of the new absolute measurements and the LaCoste-Romberg available data in the European Calibration Line (ECL) has been computed. The comparison between the ECL adjusted with the absolute data and that in the IGSN 71 system did not show non-linearities in the World Gravity Net : the found differences are within the limits of the accuracy of the comparison.

Concerning this item two papers were distributed :

- "Preliminary comparison between IGSN 71 and the new absolute measurements in Europe".
- "First order gravity net in Italy".

by I. MARSON & C. MORELLI

PROGRESS ON THE DEVELOPMENT OF A PORTABLE ABSOLUTE GRAVIMETER

James E. Faller,* Robert L. Rinker and Mark A. Zumberge

Joint Institute for Laboratory Astrophysics
National Bureau of Standards and University of Colorado
Boulder, Colorado 80309

Abstract

At the Joint Institute for Laboratory Astrophysics we are developing an absolute gravimeter using the method of free fall. Our goal is to devise an easily portable apparatus that has a 1-3 μgal sensitivity and which requires less than half a day per measurement (including set up) to obtain that accuracy. Significant progress toward this goal has been made.

* Staff Member, Quantum Physics Division, National Bureau of Standards

Having long been important in the field of standards, the value of g also provides a new tool to aid our understanding of motions of the earth's crust. To be sensitive to vertical motions at the centimeter level, gravimeters need to have the ability to discern changes in g of several μgal (1 gal = 1 cm/sec^2) which corresponds to a few parts in 10^9 accuracy. Although relative gravimeters can achieve this requisite μgal level of sensitivity in the short term, they run into serious difficulties (drifts, screw errors, tares, etc.) when they are used over time scales which are long enough for geodynamic studies. Indeed, it is often unclear whether their data show real geophysical effects or instrumental variations. The increased time and added costs required for the repeated and multiple observations suggest that perhaps an alternative or complementary approach is needed. To this end, an absolute and portable gravimeter with a several μgal accuracy would not only be useful to provide the calibration for these relative gravimeters but also, for some applications, to replace them entirely.

Since the 1960's, modern absolute gravimeters have consisted, basically, of a freely moving retroreflector (corner cube) and a fixed retroreflector comprising the two arms of a Michelson interferometer (see Fig. 1). The acceleration of the moving retroreflector is determined by counting the number of interference fringes seen by a photomultiplier during preset time intervals referenced to a precision clock. The requirements for accuracy are (1) that the only acceleration imparted to the falling object is that due to gravity and (2) the acceleration of the stationary corner cube be zero. To extend the accuracy of such devices beyond the parts in 10^8 level, one needs to address (among others) two particular effects residual air resistance and ground motion.

Even with the high vacuums (10^{-7} - 10^{-8} mm of Hg) that are today rather straightforwardly available, residual air drag on the object if one simply chooses to let it fall remains (at the μgal level) somewhat of a concern (at the best a technical pain) unless one chooses to use the mechanically more complicated method of rise and fall. In our apparatus, we have chosen the (simpler) straight free-fall approach, and are addressing the air-drag problem by surrounding the falling object with a coaccelerating chamber which serves to keep the residual air molecules moving with the falling object. At the start of each drop an initial separation between the two is caused to take place after which this separation is kept (servoed) constant.

At the start of each drop, the falling retroreflector sits on a kinematic seat in the bottom of a closed chamber. When the dropping mechanism is activated, a servo motor accelerates the chamber downward along a vertical track so as to center itself on the falling object inside, which results in the retroreflector "floating" within this co-falling chamber. Since this retroreflector is now falling with rather than through the (residual) gas molecules, air resistance is effectively removed.

Preliminary tests (at atmospheric pressure) show that this "drag free" technique reduces the sensitivity to air resistance by at least 3 orders of magnitude. [Using an antiquated, but for this purpose adequate, data handling system, we find that the use of the drag free enclosure even without any evacuation results in a value for g which agrees with the known value at our site to 4 parts in 10^6 -- the accuracy limit of the present electronics. Without the co-falling chamber the measured value of g is off (due to the air resistance) by 3 parts in 10^3.] This drag free approach also has the advantage of decreasing the drop-to-drop measurement time for two reasons.

First, the strict vacuum requirement is greatly alleviated allowing us to use a fore-pump vacuum and hence cut down the set up time. Certain mechanical difficulties (i.e., stiction and vacuum welding) associated with very high vacuums are also removed. And second, since the servo chamber is also used to catch (in a controlled fashion) and return the dropped object to its starting position (by driving the carriage back to the top), this permits us to carry out a drop as frequently as once every 3 seconds.

We spent considerable time investigating systems in which the falling chamber was not actively driven (servoed) to track the falling object but achieved (approximately) constant lift off by a variety of mechanical means. In these tests a chamber containing the dropped object was suspended by an electro-magnet and dropped by interrupting the current. Separation between falling object and falling chamber was induced by a spring-loaded auxiliary mass. However, eddy currents and residual magnetic forces were found to impart differential velocities to the two falling bodies and after many months of investigation this approach with its attendant possibility of systematic errors -- certainly at the parts in 10^9 level -- was abandoned in favor of the servo-driven "drag free" approach.

The second problem on which we have been working is that of removing sensitivity to ground motion. The falling object is, of course, unaffected by these motions; but the same cannot be said for the retroreflector in the reference arm of the interferometer. Since the non-falling parts of the interferometer rest directly on the earth's surface, the ever-present microseisms will introduce errors in the measured (apparent) acceleration of the freely falling object. A new type of isolation system (see Fig. 2) that we have developed should substantially reduce this effect.

It is well known that a mass (which we make to be the reference retro-reflector) suspended vertically from a spring is isolated from driving motions for periods which are much shorter than the mass-spring system's natural period. Since microseisms have a maximum amplitude at approximately a 6 sec period, for reasonable isolation one needs a system with a natural resonance of at least 60 sec. This, however, would require a simple spring 1 km in length and hence seriously threaten the portability of any device using this straightforward method of isolation. We have, however, electronically synthesized a very long spring by electronically terminating a spring of tractable length (30 cm) to act in every way like a 1 km (or longer) spring.

To understand this electronically generated "super spring," imagine you have, say, a 1 kg mass hanging on the end of a spring which extends 1 km vertically. This mass will oscillate up and down with a period of 60 sec and as it does the coils of the spring will oscillate up and down also. The coils very near the mass will have an amplitude nearly equal to the amplitude of the mass and the coils that are far away from the mass will have an amplitude less than that of the mass. In fact the coils near the top will hardly be moving at all. Now if one were to grasp the spring 30 cm above the mass and move that point on the spring just as it moved when the entire mass and spring was in free oscillation, the motion of the mass would remain unchanged. Having done this, one could then cut off the top of the spring and have left a spring 30 cm long that behaves in all ways exactly like a spring 1 km long. Our "super spring" uses a servo system to generate such a virtual point of suspension.

We expect that taking advantage of these two techniques will permit us in the next few years to push the sensitivity of a gravimeter based on the absolute free-fall laser interferometric technique to a few μgals.
Such an instrument having inherent stability, since it is directly referenceable to the absolute standards of length and time, would provide a much-needed stable reference for use with relative gravimeters and in some applications a direct field replacement for them.

This work has been supported by the National Bureau of Standards, the Air Force Geophysics Laboratory, and the United States Geological Survey.

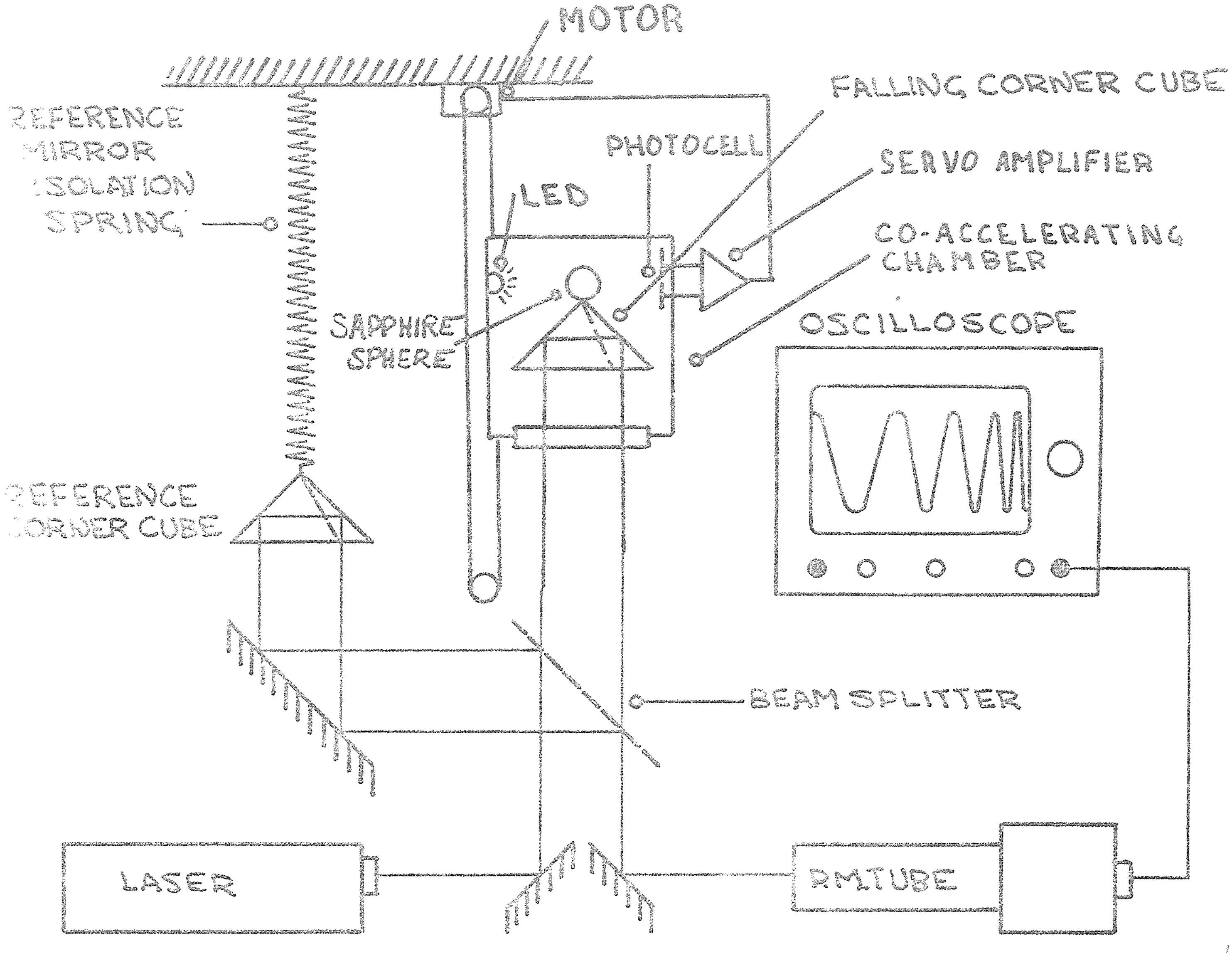

FIG. I LASER INTERFEROMETER SYSTEM

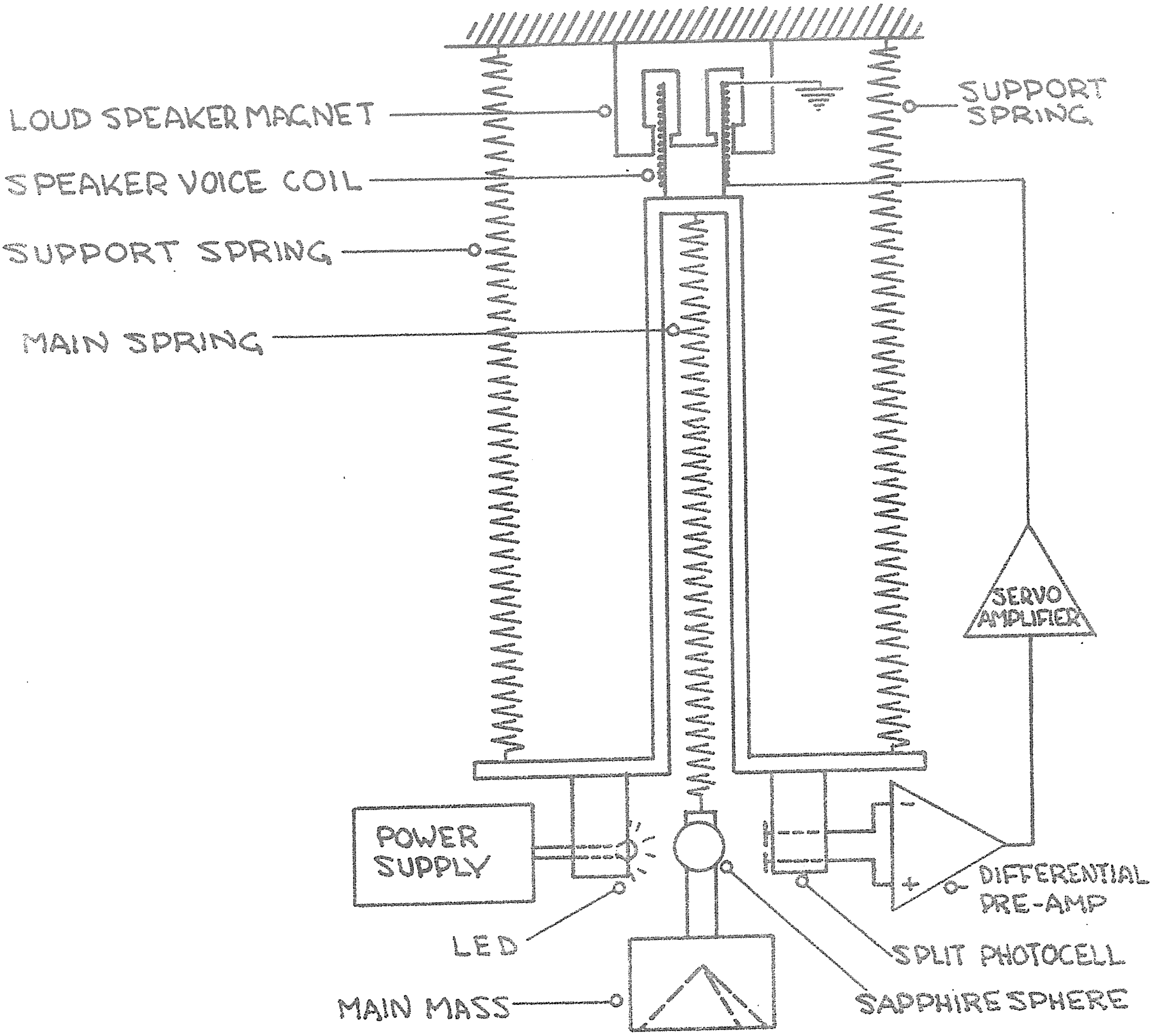

FIG. 2 SUPER SPRING

Item V - GRAVITY MEASUREMENTS AT SEA

Chairman : Dr. J.M. WOODSIDE

One session held on Thursday 14 September 1978, 2.55 - 3.50 p.m.

The primary topics of interest for discussion during this session were:

1. Instrumentation - many old sea gravity systems are either being replaced or refurbished and there are some new instruments which have been under development since the last meeting.

2. Accuracy of measurements, methods of assessing accuracy especially in compiling large bodies of data of varying quality (e.g. quality which varies in time because of navigational and instrumental improvements), and standards to use in designing survey procedures.

3. Better accuracy of navigation and the problem of how to obtain the optimum navigation, and

4. New methods of analysis and interpretation of data.

Due to the unfortunate but unavoidable reduction in time allotted for this session very little discussion on any of these topics was possible apart from brief discussion following various presentations. All the speakers touched briefly on some aspects of these topics however.

Many organizations are currently making, or have just made, decisions regarding the sea gravity meters which they will be using in the future. Since the last meeting, Bodenseewerk has taken over the production of Graf-Askania meters and now offers two types of system: 1) the Kss-30 system uses what was called previously the Gss-3 (now Gss-30) sensor mounted on a newly developed gyro-stabilized platform (KT-30), and 2) the Kss-5 system utilizing a Gss-20 sensor (previously Gss-2) on a KT-20 platform (an upgraded version of the Anschutz platform previously used) can be obtained either by having an old Gss-2 meter and Anschutz platform modified or by obtaining the complete system new. The Vening Meinesz Laboratorium in Utrecht recently had their Gss-2 meter upgraded and integrated into a Kss-5 system; and Dr. Strang van Hees of the Geodetic Institute, Delft, discussed some of the results obtained from the deployment of the new system in a detailed survey of a portion of the mid-Atlantic Ridge between 12°N and 18°N. As for the Kss-30 system, to date there is little information regarding results of its operation; however, a Gss-3 has been operated by the Institute of Geological Sciences (I.G.S.) in Britain (on a British platform) and brief comment was made on this by Mr. McQuillin. Of course, little can be concluded from the I.G.S. experience regarding operation of the Gss-30 as part of the complete Kss-30 system. Mr. McQuillin also presented some excellent gravity data from the U.K sector of the North Sea where a survey with a grid spacing varying between 8 and 15 km had produced crossover discrepancies routinely of the order of 1 mgal. The preliminary data, contoured at 2 mgal as 1:250,000 scale Bouguer gravity maps, were posted for examination by the participants at the session. Most of the I.G.S. data were obtained using a LaCoste-Romberg gravity meter (S75). A new linear LaCoste-Romberg gravity meter is promised to be available in the near future. Apart from the Bodenseewerk and LaCoste-Romberg meters, the only other major commercial contender is the Bell-Aerospace BGM-3 system (which supercedes the BGM-2 referred to during the last meeting). No gravity results obtained by the BGM-3 have been published to date. The Tokyo Surface Ship Gravity Meter (TSSG) is referred to in the national report of the Geodetic Society of Japan and the National Committee for Geodesy and Geophysics of Japan and would seem to be of about the same accuracy as the LaCoste-Romberg. With regard to the Soviet sea gravity meter, Prof. Boulanger made a short presentation on the results of sea gravity measurements carried out by the USSR. Although Dr. Bowin was unable to attend the meeting, he sent a long letter to Dr. Morelli outlining recent operations with the Woods Hole vibrating string gravimeter (VSA gravimeter) including deployment on a Taiwanese research vessel, a barge on Lake Tanganyika, the research submersible ALVIN (an unsuccessful experiment because steering motion of ALVIN tended to be too severe for the pendulus mounting of the sensor), and a C-54 aircraft (analysis of the results from this experiment being continued at present). The U.S.A. National Report also contains reference to these experiments with the VSA meter.

Although the new instruments are capable of dynamic accuracies of 1 mgal or better, the requirement for recovery of surface gravity data with a precision an order of magnitude better is still restricted by navigational accuracy (especially short-term accuracy for determining the Eötvös correction). Fortunately, navigational accuracy and repeatability are much improved over continental margins where perhaps one of the most stringent requirements for high accuracy gravity data is for use in determining the quasi-stationary sea surface topography at wavelengths less than 1000 km. Navigational techniques and improvements have been surveyed recently at meetings such as the 1977 Congress of Surveyors in Stockholm, for which reports are available. At Bedford Institute of Oceanography (B.I.O.) encouraging results have been obtained in previously problem areas (like Baffin Bay) by extending LORAN-C coverage using skywave tracking. The Navigation Group at B.I.O. has also developed an integrated navigation system (BIONAV) which combines satellite navigation, passive ranging LORAN-C, ship's log and gyro, as well as other inputs such as propeller pitch and RPM, using the strengths of one system to compensate for weaknesses in the other systems. Computerized integration of the various inputs to BIONAV is optimized by taking into consideration their different error characteristics (partly by Kalmän filtering). Very little new instrumentation is required for BIONAV; "smart" microprocessor interfaces provide the link between existing navigational equipment and an HP 2100 computer where final fix processing is carried out. Improved accuracy, reliability, and flexibility are the goals of the new system and it is hoped to be able to obtain real-time Eotvos corrections for application to the gravity signal following filtering to match the damping characteristics of the gravity meter.

One of the main innovations in the interpretation of gravity anomalies at sea has occurred in the analysis of longer wavelength gravity anomalies and their relationship to residual depth anomalies as a function of wave number. Increased quantity of data of good quality and increased computer power has aided in this work which is perhaps the only geophysical method of investigating the nature of flow in the mantle associated with the movement of plates (in the framework of plate tectonics). The gravity and elevation anomalies resulting from vertical forces in the mantle being applied to the plates are unlikely to be masked or strongly affected by the plates themselves. These studies, which also provide insight into the thickness of the plates and their rheologic properties, suggest that the idea linear LaCoste-Romberg gravity meter is promised to be available in the near future. Apart from the Bodenseewerk and LaCoste-Romberg meters, the only other major commercial contender is the Bell-Aerospace BGM-3 system (which supercedes the BGM-2 referred to during the last meeting). No gravity results obtained by the BGM-3 have been published to date. The Tokyo Surface Ship Gravity Meter (TSSG) is referred to in the national report of the Geodetic Society of Japan and the National Committee for Geodesy and Geophysics of Japan and would seem to be of about the same accuracy as the LaCoste-Romberg. With regard to the Soviet sea gravity meter, Prof. Boulanger made a short presentation on the results of sea gravity measurements carried out by the USSR. Although Dr. Bowin was unable to attend the meeting, he sent a long letter to Dr. Morelli outlining recent operations with the Woods Hole vibrating string gravimeter (VSA gravimeter) including deployment on a Taiwanese research vessel, a barge on Lake Tanganyika, the research submersible ALVIN (an unsuccessful experiment because steering motion of ALVIN tended to be too severe for the pendulus mounting of the sensor), and a C-54 aircraft (analysis of the results from this experiment being continued at present). The U.S.A. National Report also contains reference to these experiments with the VSA meter.

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The only paper dealing specifically with data accuracy was by Dr. Shih who was unfortunately unable to be present; however, his paper was tabled for discussion and will be published in a forthcoming issue of the Bulletin d'Information. The technique used by Shih in evaluating the more than 2,000,000 gravity data points along more than 800,000 km of ship's tracks off eastern Canada is to use what he has termed 'pseudo-crossover' analysis. The data are examined either by cruise or by area by investigating the consistency of data points falling within a sufficiently small area (say 1.1 km, or 1' of latitude, square) but not obtained from the same ship's track (i.e. separated in time by at least 10 minutes to ensure consecutive points are not compared). Continuing investigations will check the relationship between 'pseudo-crossovers' and real crossovers and the sources of error. So far the results have been encouraging from the point of view of detecting levelling errors in surveys, identifying regions of high quality gravity data which can be used for checking gravity meter performance at sea, and checking past surveys by modern standards.

There is clearly a need to maintain sufficient time for discussion of marine gravimetry at these meetings despite the reduced interest apparent from the disbanding of Special Study Group 3.20, and despite the increasing interest in satellite gravimetry. Certainly the sea gravity measurements can compensate for the current blind spot in satellite measurements of anomalies at small wavelengths and amplitudes, and provide the ground truth necessary for such satellite measurements. The sea measurements remain important for detailed surveying, especially over the continental margins.

J.M. WOODSIDE

Item VI - NON-TIDAL VARIATIONS OF g

Chairman : J.D. BOULANGER

Two sessions held on Wednesday 13 September 1978, 4.30 - 6.00 p.m.
Thursday 14 " 9.30 - 10.45 p.m.

Report of the President - Special Study Group 3.40, IAG
Prof. J.D. BOULANGER

BRIEF REVIEW OF RESEARCH ON NON-TIDAL GRAVITY VARIATIONS 1974 - 1978

The study of non-tidal variations of gravity is one of the important problems of modern gravimetry, intimately related with the solution of problems of global geodynamics. In fact, rapidly developing research in this field requires precise knowledge about gravity variations of both regional and global character. In particular, spectacular progress of satellite geodesy, associated with fast improvement in precision, leads to the necessity of having reliable information on the possible displacement of the gravity center of the Earth in the system of coordinates fixed on the lithosphere. Future global studies of gravity variations, combined with the data on the irregular rotation of the Earth, can provide us with new data on the physical properties of the crust and mantle and on the processes going on in the Earth's interior.

Metrology of relative gravity measurements, in cases when calibration of instruments is undertaken mainly on standartising test-areas, requires a definite answer to the problem of stability of gravity on these polygons.

Continuously growing accuracy of physical standards, whose value is determined by gravity data, demands precise knowledge of stability or instability of gravity at calibration point.

The measurements of gravity field variations in time are an extremely important stock of knowledge for geophysics, geodesy, astrometry, celestrial mechanics, geology, physics, and many other natural sciences.

As commonly acknowledged, Prof. BARTA, in his many works, gave the theoretical basis of the possible gravity changes of global character. However, his concepts of the order of the possible gravity variations were not confirmed experimentally. This phenomenon is almost unstudied. There is very little information on its demonstrations being the result of short-term and small number of series of observations. As yet, there is only one established, but far from reliable, fact of gravity change by the order of 50 microGal, obtained at Sèvres. Moreover, it is not clear, whether this event is of global, regional or local character /9/.

Estimation of the possible gravity variations on the Earth's surface, caused by reconstructions in the Earth's crust, produces values in the order of 5×10^{-2} microgal/y. /35/. The yearly movement of the Earth's poles due to free nutation in middle latitudes is evaluated by about 15 microGal /41/.

The calculations made by PARIISKY and MOLODENSKY have shown that gravity values may change within 1-2 microGal as the result of the irregular rotation of the Earth /6/. Analogical calculations were made by LINDIGER /58/. The influence of deformations going on in the Earth's interior on gravity were evaluated by WALSH /76/.

The seasonal changes of the level of the World Ocean cause the displacement of the center of the Earth's mass, thus leading to global gravity changes on the Earth's surface to 0,6 microGal /69/. Global movement of atmospheric masses of the Earth may alter gravity values up to 1.3 microGal /70/.

Movement of masses caused by the sum of geodynamic phenomena can result in the displacement of the gravity center of the Earth by 10 mm, which fact in its turn may lead to gravity variations on the Earth's surface by the value in the order of 2-3 microGal /69,70/. These calculations, however, are largely approximated and need further improvement. For this purpose it is necessary to carry out both theoretical and global observations of gravity changes with simultaneous determinations of vertical movements of the Earth's surface /54/, /57/.

During recent years the studies of regional and local gravity variations have considerably developed. Theoretical evaluations of the effect of short-term and seasonal displacements of atmospheric masses on regional and local scales allow to conclude that these disturbances can reach values in the order of 20-30 microGal /13, 14, 15, 77/.

Periodic and non-periodic changes in the level of ground waters, changes in the volume of water in closely located basins, artesian basins and other hydrological effects can cause disturbances of gravity in the order of 7-8 microGal. In some cases these effects can exceed 100 microGal and reach 500 microGal /10, 11, 40/. The effect of ground water level caused by sea tides ...

has been established /49/. The effect of changes in the river water level on value W_{xz} has also been determined /3/.

At the present moment much attention is drawn to the study of non-tidal gravity variations on geodynamic polygons. One of the best examples of such observations is the research conducted on the territory of Fennoscandia (53). The basic purpose of this research is to study the mechanism of the uplift of the Earth's crust in that region.

The first traverse of the polygon, about 1200 km long, stretched from the coasts of the Atlantic to the eastern boundary of Finland. Later traverses were drawn to the north of the first one, crossing the region with maximal rates of vertical crustal movements, passing through Sweden and Finland /55/. In the process of measurements different factors affecting instrumental recordings were carefully taken into account. Particular attention was paid to the study of the scales of gravity meters. In order to as much as possible eliminate errors the observation points were chosen in such a way that the differences in gravity values between the nearest points would not exceed 0.5 microGal. Measurements were made by a group of instruments LCR/model G/. Though the measurements were made with very high accuracy /more than ±2 - ±3 microGal/, the results characterising gravity changes due to geotectonic processes were unreliable. The measurements also failed to establish correlation between gravity changes and changes in the altitude of points.

A gravimetric network of high precision has been established in the eastern part of the Mediterranean Sea (±5 - ±10 microGal). Repeated measurements on that network will provide data on the stability of gravity field in this region /74, 75/.

The study of non-tidal gravity variations in Japan was started in the 1950's and was further developed in the 1960's. Then the accuracy of ± 0.03 mGal was achieved. Later, as the result of a detailed study of instruments the accuracy of ± 0.01 mGal was reached by the measurements with a group of the LCR gravity meters /45, 52, 65, 72, 80/.

In the region of the Hokkaido Island during 1952-1975 measurements were repeated 10 times. The last 5 measurements were made after a strong earthquake on the Miura Peninsula. As the results maps, showing gravity changes for the time intervals 1962-1973, 1973-1974, 1974-1975, were compiled. The first two maps represent variations reaching 0.25 mGal, the third map those reaching 0.03 mGal. The observed increase of gravity correlated with considerable subsidences of the Earth's surface /65, 73/.

At the Izu peninsula 4 years after the earthquake gravity values increased by 40-60 microGal /50/. Gravity variations connected with earthquakes were recorded in other regions as well /51/.

Around the Biwa Lake at 46 points of a closed network about 160 km long repeated gravity determinations were made six times almost simultaneously with levelling. According to these data, the mean rates of gravity variations are characterised by values from 0 to 15-20 microGal/y. and have a satisfactory agreement with the vertical movements of the Earth's surface /6,59,64/.

Repeated observations, carried out on the Kii peninsula from 1972 to 1974, have fixed gravity variations reaching 12 microGal/y. ± 8 microGal /59,60,61,62,63/.

Near Tokyo along the coasts of the Miura and the Boso peninsulas, with intensive local subsidences of the Earth's surface, increase of gravity values was established at the rate of about 20 microGal/y. These variations correlate well with the decrease in heights /72/.

The values of gravity for Tokyo, as compared to Kakioka, from 1960 to 1963 were reduced by 0.08 mGal (11 microGal/y), which fact was the result of lowering of ground water level by 12m From 1969 to 1974 the water level continued to go down, but gravity values did not change. In 1974-75 the increase of gravity by 0.05 mGal (18 microGal/y.) was observed; at the same time, the level of ground waters rose by 6 m /52/.

In north-eastern Iceland, in the zone of active volcanoes, observations of gravity changes were started in 1938. The first results were unconvincing due to low accuracy. More reliable data were obtained in 1965 and 1970. At all points of the observation network the changes of gravity did not exceed 0.05 mGal for 5 years /66,67/.

In the GDR, in 1970, a gravimetric polygon about 200 km long was established from Magdeburg to Frankfurt-am-Oder. The differences of gravity values between adjacent points do not exceed 13 mGal; the difference between the extreme points are 0.6 mGal. Measurements were made in 1970, 1971 and 1972. Detailed hydrological research was undertaken simultaneously with the gravimetrical studies, i.e. ground water level was determined, as well as porosity and water content of soil. The interpretation of the data obtained allowed to conclude that the observed gravity changes are very small and can be attributed to hydrological effects /42,43,46/.

In the FRG, to the north of Darmstadt a network of gravimetrical points spaced 1-6 km apart, was set up on the area of 10,000 km^2. The accuracy of the network is evaluated by several hundredths of mGal. There were obtained no reliably established changes of gravity. It is planned to repeat measurements every 2-3 years in future /47/.

On the territory of Czechoslovakia two polygons were set up in 1967 for the study of gravity changes: one of them, 750 km long, is stretched along the parallel, the other, 200 km long, is stretched along the meridian. Four repeated measurements by the Sharpe gravity meter set established a network with the mean error of determination of the point $\pm$ 17 microGal /68/.

The observations, conducted on the Australian calibration gravimetrical basis, from New Guinea (Papua) across the continent to Tasmania, during 1970-1971 and in 1973, produced no reliable measurements of gravity changes. If they exist, their value does not exceed 4-5 microGal/y. /78/.

The USA national basic gravity network, composed of 59 points, was set up in 1966-1977. Repeated observations were made in 1975. According to preliminary data, during nine years the gravity field was stable within 0.03 mGal. It is suggested that for the next 10 years the non-tidal variations of gravity of regional character shall be established with the accuracy in the order of $\pm$3 microGal/y. /71/.

The data, published by Woollard show, that gravity changes reaching 0.07-0.16 mGal/y. were recorded in Mexico. These data, however, are unreliable, because measurements are compared made by pendulums with measurements made by gravity meters. In this case one may expect an essential effect of systematic errors of both methods.

Much attention is given to the measurements of non-tidal gravity variations on the territory of the Soviet Union. Observations are carried out on many geodynamic polygons, whose number steadily increases, At present more than 15 polygons are in operation.

Thus, on the Middle-Russian polygon with points Moscow - Petrozavodsk-Kirov-Perm-Sverdlovsk-Kazan-Moscow the gravity variations, by the measurements of 1970 and 1975, were from 0 to +0.04 mGal; this can be attributed to the accretion of measurement errors /19/.

On the territory of Ukraine, Moldavia and the Crimea, during 8 years gravity changes were measured within the range from - 0.58 to + 0.40 mGal. However, these data are metrologically unreliable /32, 33,34,40/. On the basis of these data an attempt was made to establish correlation ties between gravity changes and solar activity /29,30,31/.

Systematic repeated observations are made on the Moscow polygon /18,37,38/, in the Caucasus on the Dombay /36/ and the Baksan polygons /2,36,38/, in the region of Baku /16,17/, in Armenia /27/, in different regions of Georgia /1,5/, on the Alma-Ata polygon /22,23,39/, on the Ashkhabad polygon /8,20,21/, on the territory of Estonia /28/. However, despite detailed measurements no changes of gravity were detected that would considerably exceed the mean errors /40/.

On the Pripiat polygon a good qualitative correlation was obtained between gravity changes and the vertical crustal movements. But there is no quantitative correlation.

Repeated measurements have been for a long time carried out in the rift zone of the Baikal geodynamic polygon /24,25,26/. There also no changes of gravity were observed exceeding mean errors of measurements.

At the Garm geodynamic polygon the gravity changes are measured during many years with the purpose of establishing correlation between the vertical crustal movements and gravity variations.

The changes observed there are small, in the order of the measurement errors, and cannot be correlated with vertical movements, which in that place reach 10-15 mm/y. /7/.

Repeated absolute gravity determinations carried out at the international gravimetrical point Ledovo, evidence to a high stability of the field. All discrepancies lie within measurement errors and deviations from the average do not exceed 6 microGal. Though the observations were conducted in summer, autumn and winter, seasonal gravity changes were not detected /9/.

Analogous results on high stability of the gravity field were obtained from absolute determinations in Novosibirsk /4/. There also the seasonal gravity changes were not recorded despite a thick snow cover around the geophysical station where measurements were made.

The measurements, made in 1968 and 1974 on the international gravimetric polygon with points: Tallinn-Vilnus-Potsdam-Prague-Budapest-Bucarest-Sofia, showed a fairly high stability of the field. All discrepancies were much less, than mean errors. On the whole the stability of the field is characterised by the value 3 $\pm$ 1.$\pm$2.7 microGal/y. along the whole length of the polygon.

* * *

The following conclusions can be drawn in evaluation of the general state of the problem:

- There are no reliable data as yet on the global change of gravity. The number and length of series of observations are not sufficient. In order to solve this problem, it is necessary to establish a special international gravimetrical network by means of absolute gravity meters.

- The regional gravity variations are determined with greater reliability. But often there are controversies between vertical movements of the Earth's surface and gravity variations; a good agreement is observed in several cases.

- Gravity changes are definitely fixed when caused by a combination of phenomena preceding or accompanying volcanic eruptions /65/; in a number of cases the changes in the gravitational field were recorded after strong earthquakes.

- There are numerous communications about observations of considerable gravity changes without appropriate metrological evaluation of the used results. The analysis of world literature shows, that the higher is the precision and the more improved is the technique of measurements, the less are the recorded variations /48/.

In 1977, in Trieste, at the invitation of the National Committee of Italy jointly with the special Study Group 3.37, a Symposium has been held on the problem of non-tidal gravity changes. The Symposium was highly qualified and appreciated by all participants. As the co-convenor of the Symposium, I wish to express my sincere and deep gratitude to Prof. A. Marussi, the organiser of the Symposium, for the excellent arrangements.

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Prof.I. NAKAGAWA presents the following paper :

GRAVITY CHANGES OBSERVED IN THE KINKI DISTRICT, JAPAN

by I. NAKAGAWA & M. SATOMURA

Gravity measurements have repeatedly been carried out in the area around Lake Biwa in Japan since 1950 in order to detect the secular change of gravity. The results obtained so far show that gravity change observed on the south line of the first order levelling route around the lake during the period of 1971 ~ 1975/1976 was consistent with the results of levelling surveys. This evidence shows that precise gravity measurement is one of the powerful methods for detecting vertical crustal movement.

Another precise gravity measurement has been carried out at stations where the gravity value is almost equal to that of base station (Geophysical Institute of Kyoto University ; 979.70775 Gals), along the levelling route in the area covering the Lake Biwa and Kii Peninsula since 1972. Besides them, the precise gravity measurement has also been carried out at stations with the gravity value 979.686 Gals in due consideration of their distribution. However, the time interval between the first and the last measurements was so short that no significant result was yet obtained, but it is expected that the gravity values obtained through these successive measurements will give basic data for the future study on time change of gravity in the area concerned.

Dr. L. PETTERSSON presents two papers :

1. HIGH PRECISION GRAVITY MEASUREMENTS FOR STUDYING THE SECULAR VARIATIONS OF GRAVITY IN FENNOSCANDIA

In 1965 the Finnish Geodetic Institute proposed a project with the aim to study the secular variation of gravity which should be associated with the Fennoscandian land uplift. Thanks to the high accuracy obtainable from LaCoste & Romberg gravity meters, observations extended over a few decades would be sufficient to obtain values of the variations accurate enough to draw conclusions regarding the mechanism of the land uplift. At the same time it would be possible to study the attainable accuracy when making such kind of measurements. The Geodetic Institute made the first observations in 1966 at three Finnish stations on a line at approximately latitude 63°N. Since then the project has expanded considerably.: there are now four lines across Fennoscandia and, in addition to the Finnish Geodetic Institute the corresponding institutes in Denmark, Norway and Sweden, two German and one Swiss institutes have participated. The project is now planned and coordinated by the Working Group for Geodynamics within the Nordic Geodetic Commission. The next observations are planned to take place in 1980 and the work has now arrived at a stage where it can be appropriate to present a review.

....

The lines and the stations are indicated on the map, figure 1 (next page) which also shows isobases of equal land uplift. From this it can be seen that the two northermost lines run quite near the area of maximum land uplift. The land uplift values for the stations on these two lines range from nearly zero to about 8 mm/yr which should result in a maximum relative variation during a decade amounting to something between 13 and 25 μgal, if hypothesis reasonably assumed are applied. The standard error of the corresponding observed gravity difference is about ± 5 μgal.

LAND UPLIFT GRAVITY LINES
ABSOLUTE GRAVITY STATIONS

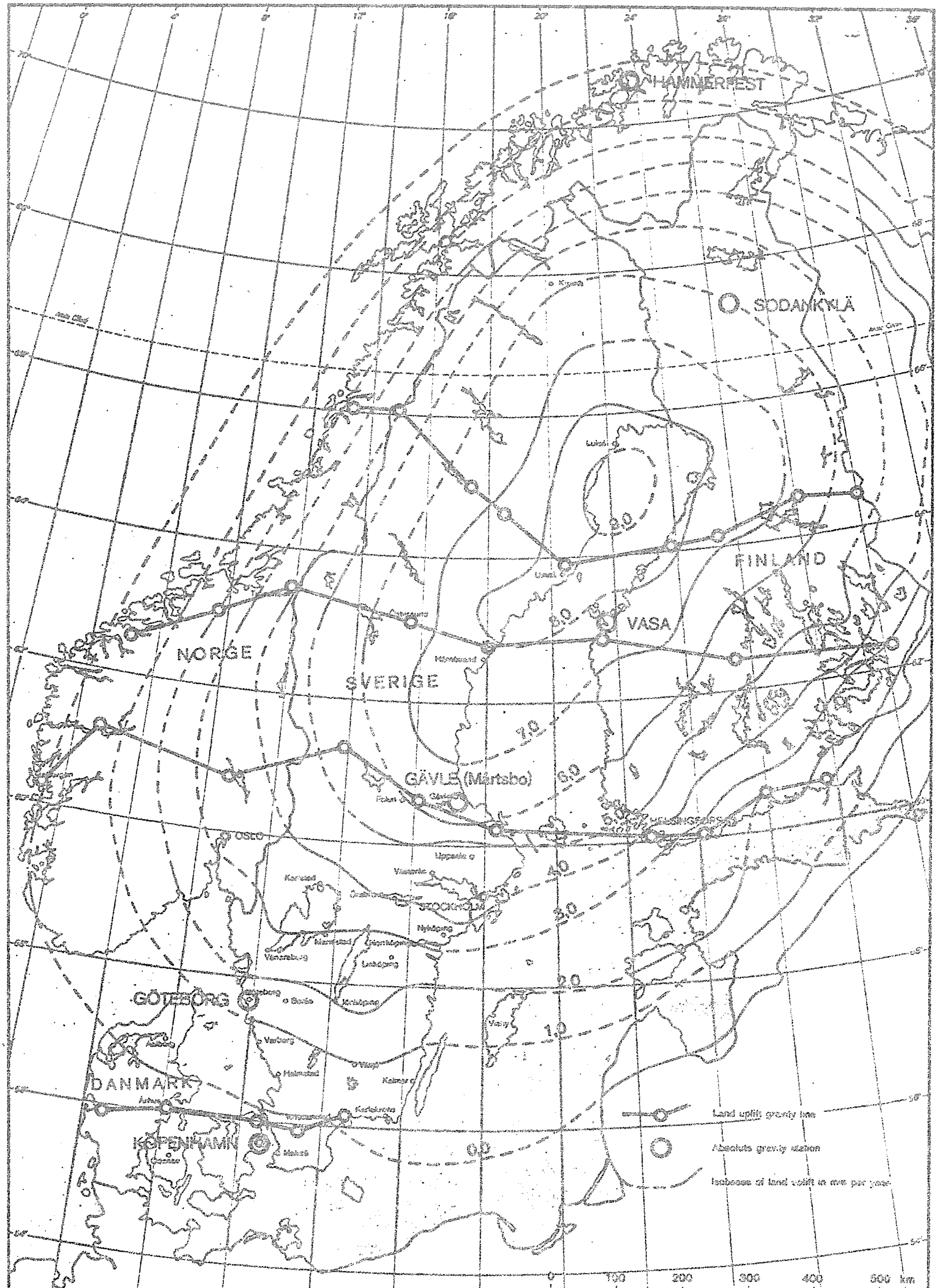


Figure 1

2. THE RESULTS OF REPEATED GRAVITY MEASUREMENTS IN NORWAY AND SWEDEN ON THE LAND UPLIFT GRAVITY LINE ALONG THE LATITUDE 63°N.

...

Repeated measurements have hitherto been carried out only on one of the lines, the 63° line. In this report some results of the measurements of the section Vågstranda - Vasa of this line will be given. There is not yet a uniform computation of all measurements. In the present study, observations by Nordic institutes only will be used, as these results are comparatively homogeneous. It must, however, be emphasized that as not all data have been used and also because all reductions of the measurements have not yet been fully investigated, the results below must be considered as preliminary.

The section Vågstranda - Vasa of the 63° line is shown on the map figure 1 (see p.I-D-17). It consists of the following stations (from west to east) : Vågstranda, Meldal, Kopperå, Stugun, Kramfors and Vasa.

On the Table 1 (see p.I-D-19) are given the gravity differences between these stations.

...

The investigation shows that it is not possible to determine significant secular gravity variations from the gravimeter observations on the section Vågstranda - Vasa of the 63° line from the observations in the years 1967, 1972 and 1977. Partly this can be due to the few measurements in 1967. But apart from this, 10 years seem to be a too short interval, as then other more or less local variations can bias the results.

Table 1. Gravity differences on the section Vågstranda - Vasa of the 63° line.

Stations	1967	1972	1977
Vågstranda			
	552.5 ± 4.6	563.7 ± 4.9	533.8 ± 4.1
Meldal			
	- 1.6 ± 10.9	5.2 ± 3.8	9.7 ± 3.6
Kopperå			
	- 74.0 ± 5.3	- 92.9 ± 2.5	- 93.8 ± 3.7
Stugun			
	52.2 ± 8.6	55.7 ± 2.5	53.6 ± 2.8
Kramfors			
	375.3 ± 4.5	369.8 ± 5.2 *)	372.5 ± 2.0
Vasa			
Number of gravimeters	3	7 *) 4	9

Dr. G. BARTA reports on :

MASS DISTRIBUTION OF THE EARTH ON THE SURFACE AND AT DEPTH AND THE GLOBAL SECULAR VARIATION OF THE GRAVITY FIELD

(See complete text p. I-D-24).

Prof. R. RAPP presents the paper of

R.S. MATHER & D.R. LARDEN

ON THE RECOVERY OF GEODYNAMIC INFORMATION FROM SECULAR GRAVITY CHANGES

Global programs for the determination of secular gravity changes can provide valuable information on geocentre motion as well as constraints for use in modelling the mechanism for mass transfers associated with lithospheric plate motion.

Numerical solutions show that meaningful results can be obtained for geocentre motion from a well-distributed global network of at least thirty absolute gravity stations from observations over periods exceeding a decade with station noise at the ± 10 μGal level.

Expected changes in the shape of the geoid per century, are computed for different mass transfer models associated with plate motion. These include some implausible models to establish upper bounds for the magnitude of gravity changes inferred from such mass re-distributions. As the changes in gravity due to this effect may be significantly smaller, the required observing period for favourable signal recovery in the presence of station noise at the ± 10 μgal level approaches 10^2 yr for most plausible models.

(Extract from : UNISURV G 29, 11-23, 1978).

Dr. A. KIVINIEMI speaks on :

THE RESULTS OF REPEATED GRAVITY MEASUREMENTS IN FINLAND ON THE LAND UPLIFT GRAVITY LINE ALONG LATITUDE 63°N.

...

Since 1966 gravity measurements on the Finnish part of the land uplift gravity line along latitude 63°N have been repeated 5 times in 11 years.

...

No secular variation in the gravity differences can be proved from the above results. On the other hand, according to the isostatic hypotheses made at the outset, the maximum decrease in the gravity difference should be 10.0 - 18.5 µGal, which is 4-7 times the standard error of one "measurement". The results, however, support a slight increase in gravity difference. Thus these results do not support either the theory of isostatic land uplift or that concerning the sinking of the geoid in Fennoscandia. No change, or an increase in the gravity at the centre of the land uplift area could be explained either by local variations in the mass distribution or by the combined effect of land uplift and of geoid uplift.

Because of the unexpected discrepancies in the gravity difference between Äänekoski and Vaasa, further measurements on this lines will be carried out in the future.

After that communication Mr. A. VOGEL mentions that :

"There are very accurate levellings repeated several times in Finland. There exists a residual uplift map of Finland by Prof. TUOMINEN. This residual map has been obtained by subtracting a regional trend of land uplift. It shows that there are residual movements of blocks which means that land uplift in Finland is irregular both in space and time. Would it not be a good idea to compare the gravity changes with this residual uplift distribution ?

Dr. J. MONGES & M. MENA (México) report on :

SECULAR VARIATIONS OF GRAVITY IN LATIN AMERICA

Important old gravity stations in Latin America have been reoccupied in search of evidence for secular variations of gravity, under Dr. G.P. WOOLLARD's direction. In those cases where some changes were found, the measurements were repeated during many years to be able to determine if the variations were real.

We present results to show that there are evidence of secular variations of gravity in some places of Latin America.

Dr. S.K. SINGH, M. MENA & J. MONGES present :

SECULAR VARIATIONS OF GRAVITY IN MEXICO

WOOLLARD & MONGES (1970) detected that the gravity was decreasing at a rate of about 0.037 mg/yr in Mexico City with respect to Madison (Wisconsin), Houston (Texas) and Monterrey (México) during 1963-1966. A local secular variation of gravity was also reported in Mexico City due to compaction of Lake deposits over which much of the city is built. Gravity data over Mexico City - Acapulco traverse indicated that in 1967 the gravity at Acapulco had increased by 2.49 mg since 1949 as compared to that of Mexico City.

We analyze the data obtained since 1967 using LaCoste-Romberg G-Gravimeters in terms of secular variations of gravity in Mexico and attempt to interpret them in terms of geology, subduction of Cocos plate below Mexico (7 to 10 cm/yr), and seismicity.

Dr. H. DREWES presents a paper :

REGIONAL SUBSIDENCE OF THE LAKE OF MARACAIBO AS DETERMINED BY REPEATED GRAVIMETRIC MEASUREMENTS

Caused by the extraction of petroleum, local subsidences have been observed by repeated levellings in the oil-field at the eastern coast of the Lake of Maracaibo. To find out the whole range of the subsidence, a gravity network of 60 stations has been established in 1977 and remeasured in 1978. The gravimetric measurements and evaluations are described, and the results are discussed.

Prof. W. TORGE and E. KANNGIESER present :

LOCAL GRAVITY VARIATIONS IN NORTHERN ICELAND CONNECTED WITH EARTHQUAKE AND VOLCANIC ACTIVITY

Monitoring of gravity variations with time in the neovolcanic zone of northern Iceland, being part of the constructive plate boundary between the European and the American plates, started in 1938. Reobservations in 1965, 1970/71, and 1975 revealed a gravity increase in the neovolcanic zone, with a maximum of 7... 8.10^{-8} $ms^{-2}/_a$, for the epoch 1965... 1975.

In 1975, a rifting episod started here, consisting of a succession of slow inflation periods and rapid subsidence events, which is still going one. The center of activity is situated below the Krafla caldera, and the rifting process is affecting the 80 km long fissure swarm associated with this central volcanoe.

Gravity and height variations connected with this process have been investigated by reobserving profiles in the Namafjall and in the Gjastikki area, situated nearly 10 km south resp. north of Krafla, as well as by the observations of a number of gravity stations in the northern part of the fissure zone, in 1976, 1977, and 1978. By repeated observations with 2 resp. 3 LaCoste-Romberg gravity meters, the accuracy obtained at each gravity survey is at the order of $\pm$ 10.10^{-8} ms^{-2}. In the profiles crossing the fissure zones, a gravity increase of more than 100.10^{-8} $ms^{-2}/_a$ has been found in the central part, while gravity at the flanks decreases at the same order. These variations are correlated with subsidence and elevation rates at the order of 0.5 m/a. From the regional gravity control along the neovolcanic zone, between the Krafla area and the sea, it has been found that gravity variations with time are of rather local character, changing their sign with a half wave-length of 5... 10 km, and reaching a magnitude of $\pm$ 200.10^{-8} ms^{-2} and more.

These results contribute to the understanding of the mass displacements in time and space in this region, occuring at the present rifting process.

Mass distribution of the Earth on the surface and at depth and the global secular variation of the gravity field

G. Barta

Summary

The paper reviews - in connection with the previous one - recent results of studies of the author concerning mass inhomogeneities of the Earth. It is well known that the gravity effect of surface mass inhomogeneities being in isostatic equilibrium is weakening more quickly with height than that of the inhomogeneities of very deep position. So we can use a differentiation according height for filtering out surface effects.

The author, having introduced an accordingly modified value of the polar flattening, has determined from the niveau levels valid for greater heights the two best approximating rotation symmetrical

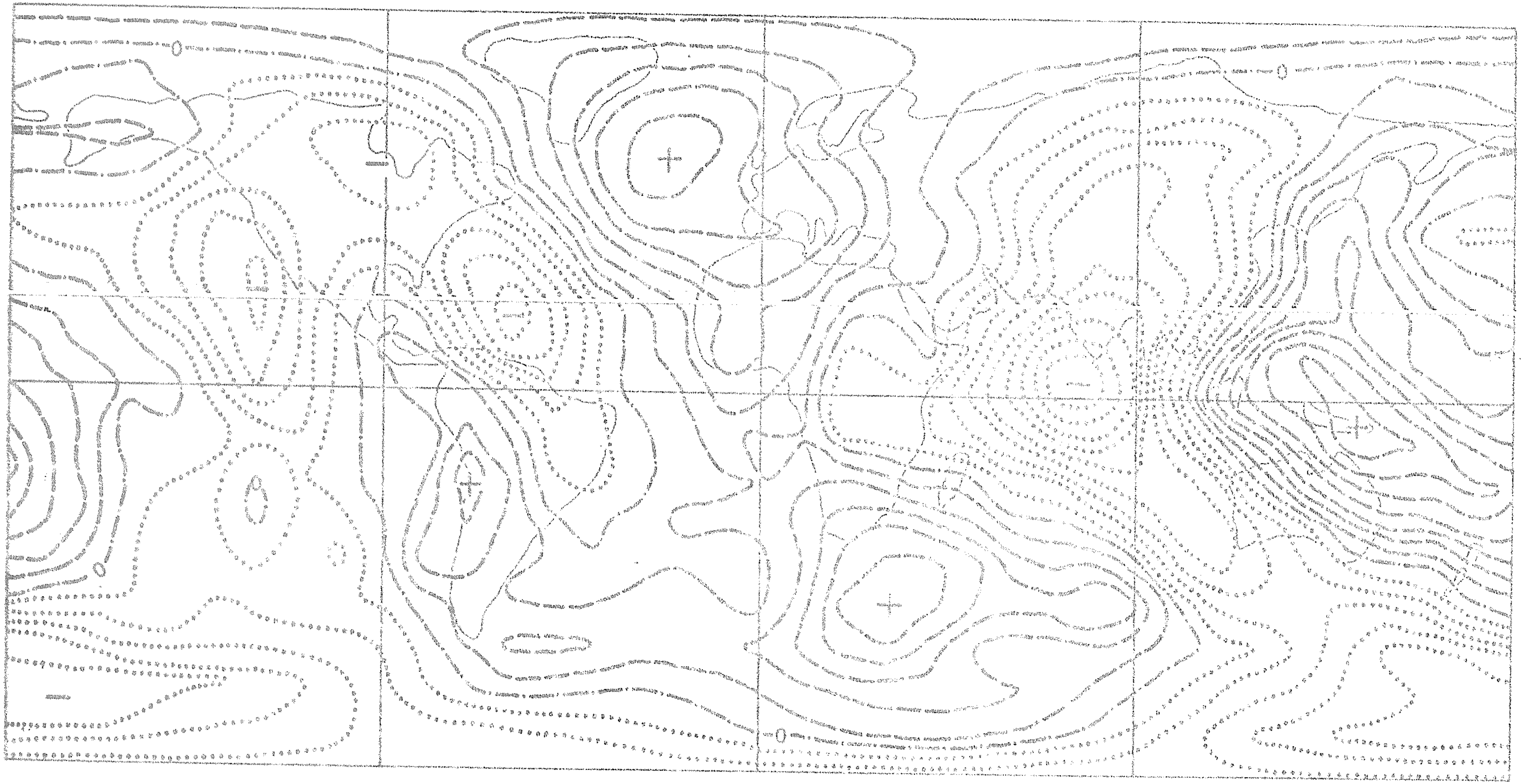
figures caused by deep seated sources /Fig.2/./The sum of the two forms gives correctly the well known difference between northern and southern hemispheres/. When reducing the observed geoid with the sum of the best approximating forms /i.e. with the effect of deep seated sources/ the remaining /residual/ geoid shows a certain correlation with the relief, so that one can suppose that the residual parts are brought about by surface inhomogeneities /Fig. 3/.

Deep seated sources - being in no connection with the relief - cause a 2/3 part of the anomalies, while surface sources bring about 1/3 of them; thus it is not surprising that the latter will be suppressed by the former ones.

One can also state from the niveau surfaces computed for greater heights that the deepest source is that causing the rotation-symmetrical anomaly coming from Australia /eccentricity of the inner core/, while that causing the India anomaly has a somewhat less deposition /being situated in the outer core/.

Supposing that the speed of change of the deep seated sources is the same as that of the westward drift of magnetic dipole the author has determined the possible amount and surface distribution of a supposable secular variation of the gravity field /Fig. 4/.

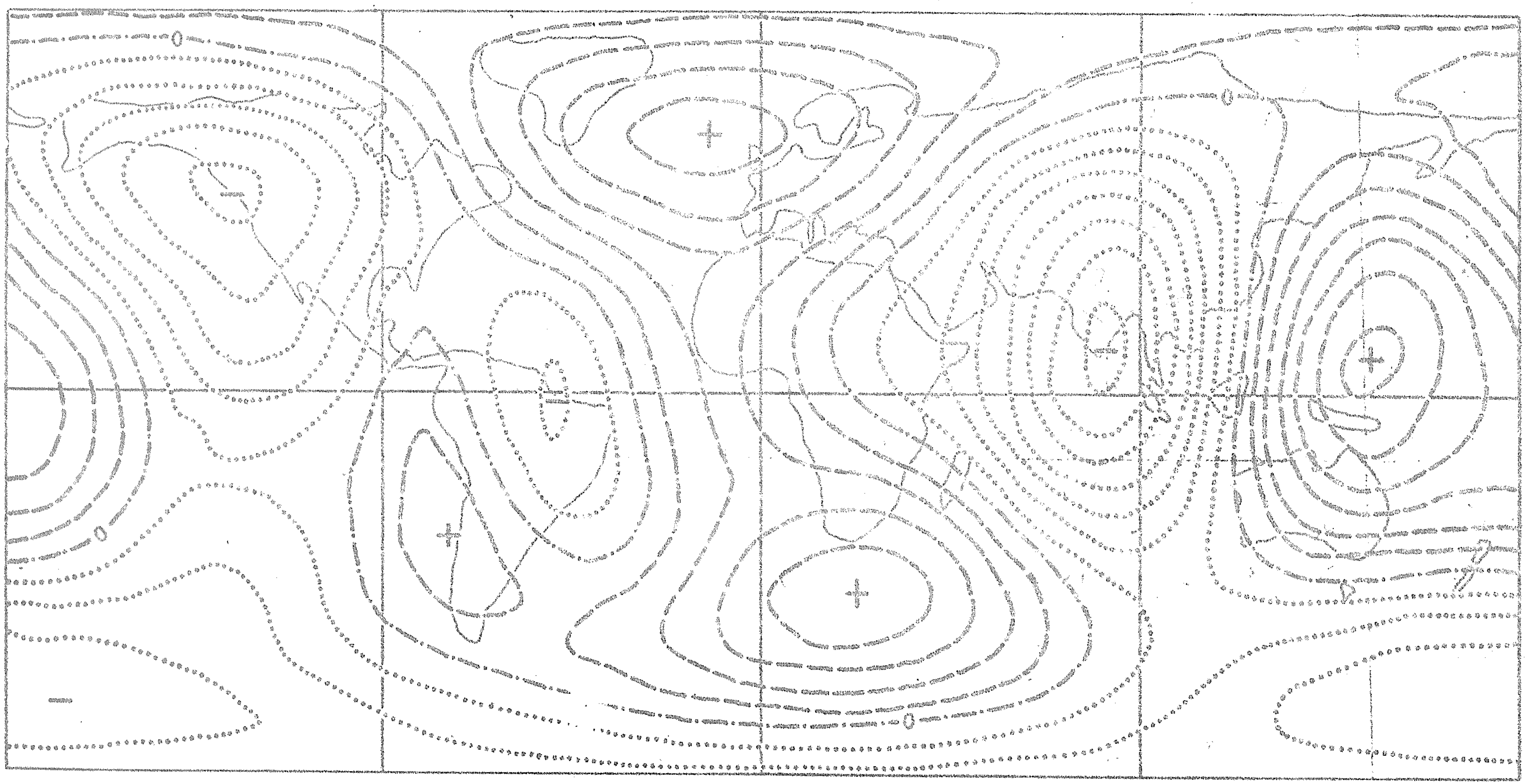
Finally the author outlines some possible and promising trends of further studies.



SE III geoid heights calculated with respect to the best fitting ellipsoid

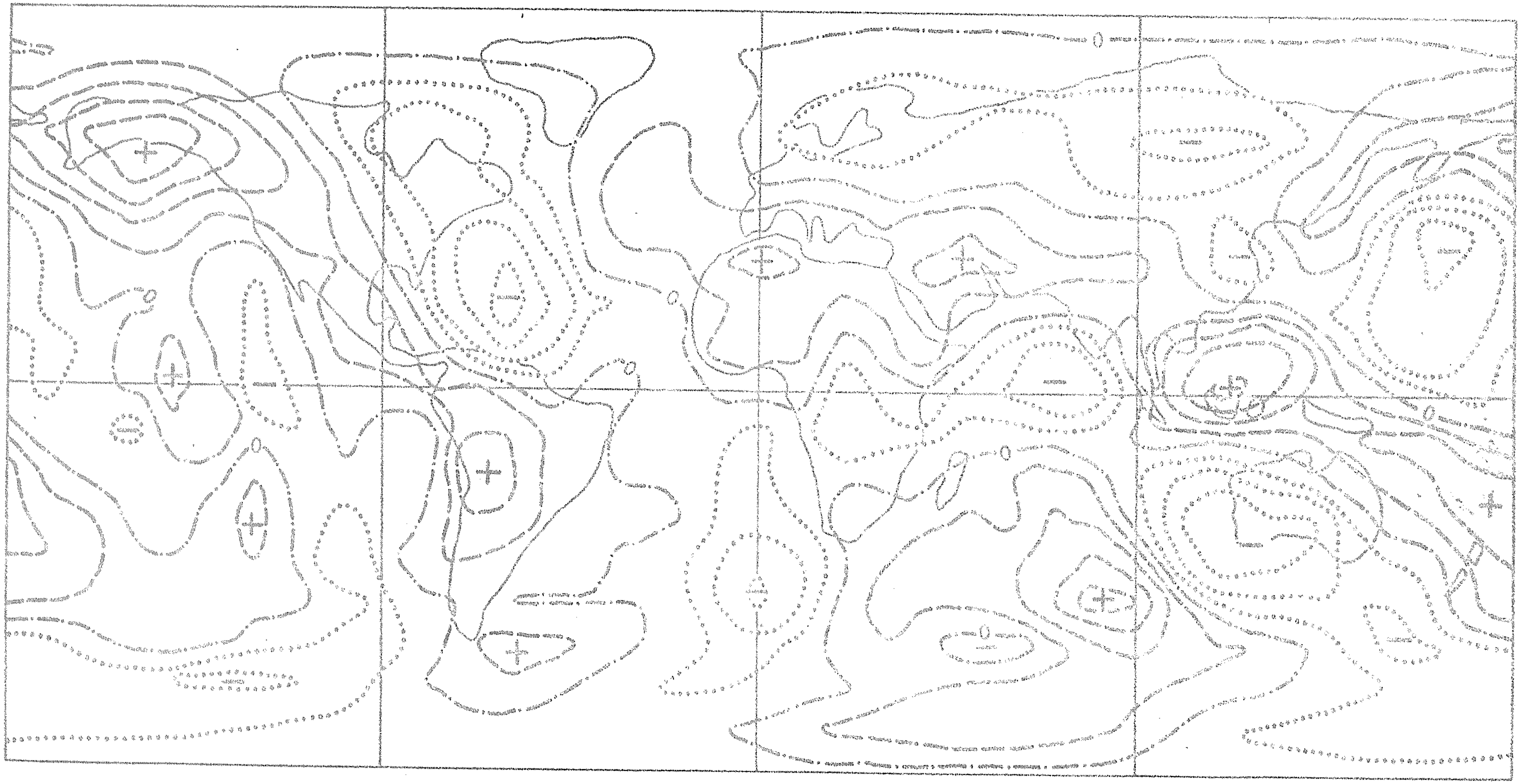
(interval of contour lines: 10 m)

Fig. 1.



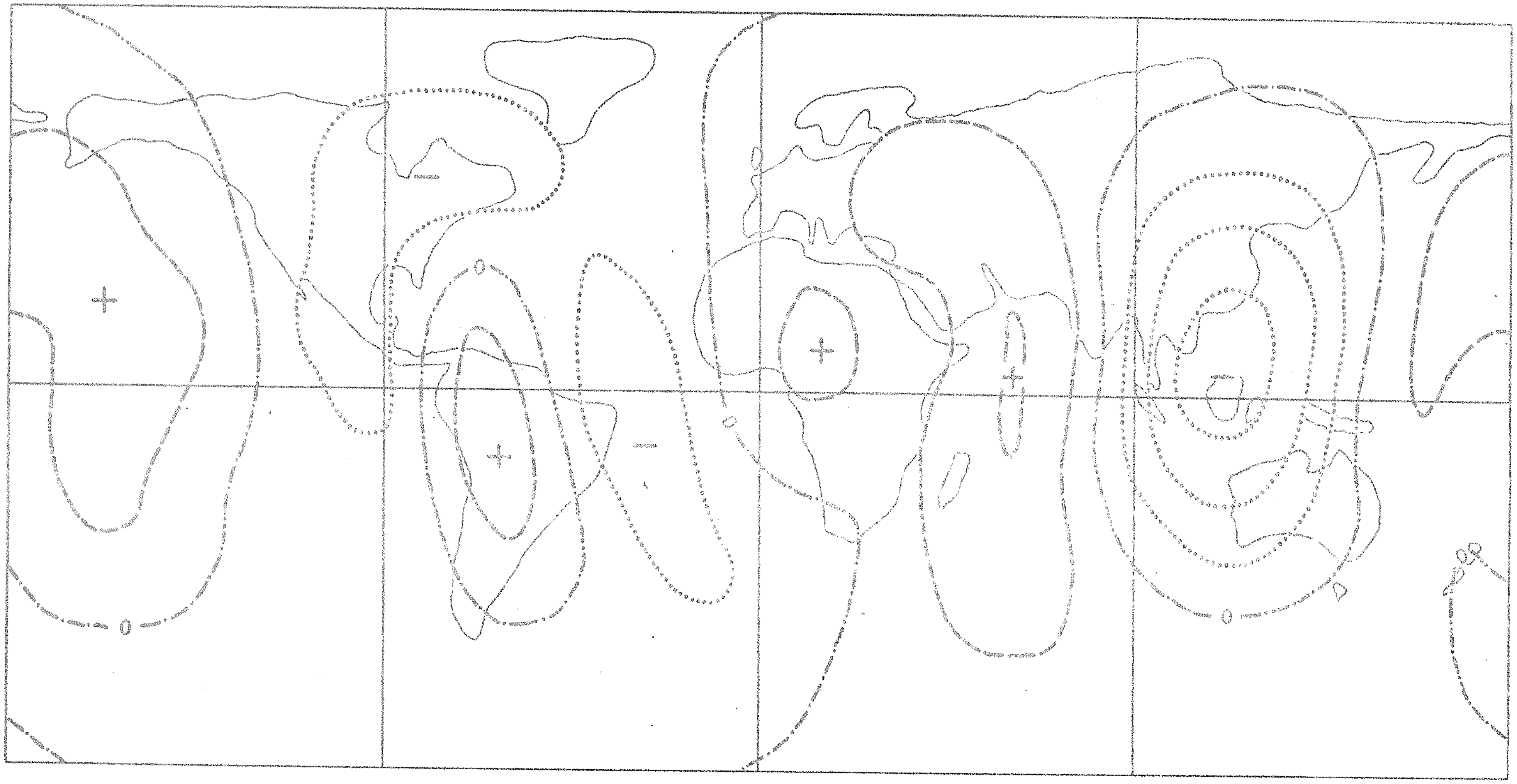
Map of geoid height of deep seated sources (interval of contour lines: 10 m)

Fig. 2.



Residual map representing the system of geoid height data brought about by deep seated sources (interval of contour lines: 10m)

Fig. 3.



Yearly variation of the g value (interval of contour lines: 20 μgal)

Fig. 4.

Item VII - HIGH PRECISION GRAVIMETRY

Chairman : E. GROTEN

One session held on Thursday 14 September 1978, 4.30 - 6.30 p.m.

Report on activities of Special Study Group 3.37, IAG

Prof. E. GROTEN

SPECIAL TECHNIQUES IN GRAVIMETRY
1974 - 1978

After the unfortunate death of the previous chairman of SSG 3.37 the late Professor T. Honkasalo, it was tried to continue his work and to pursue his ideas and his policy. By this statement it is meant that the SSG sticked to the goals set up four years ago, on one side, whereas the SSG kept track of new developments, envisaged implications of new techniques and necessities and encouraged and coordinated new and conventional approaches and research projects, on the other side. In that connection a number of new members joined the SSG. A meeting of the SSG was held in June 1977 during the Symposium on "Non-tidal gravity variations" at Trieste.
In the years before very precise gravimetry was considered as a very specialized topic which still had to prove its usefulness where, moreover, the results were rather different and partly contradictory and the spectrum of purposes was quite narrow. Meanwhile, precise gravimetry became a tool for diversified and various purposes, the results found in different countries and continents agree (to the extent they are supposed to agree) and the goals to be attacked in order to achieve still higher accuracy and to enlarge the spectrum of applications can be clearly defined. It is obvious that with achieving accuracy which is sufficient for various purposes the problems and goals of SSG 3.37 become more complex, e.g., stationary observations and related techniques are more important than earlier and the interrelations with supplementary and competitive techniques need careful considerations. In global and regional applications the new techniques have to be based on repeated absolute gravity measurements. Thus the progress in SSG 3.37 depends to some extent on progress in that field, too. Typical examples of such new aspects in high precision gravimetry are the detailed study of environmental effects ; the cryogenic ...

gravimeters as operated by Prof. Goodkind/San Diego enable the detailed analysis of effects of air pressure variation on precise stationary gravimetry; Dr. A. Lambert/Ottawa studied ground water table variations and achieved very high accuracy in a local net. Even though similar work was carried out using conventional equipment in connection with tidal studies by, e.g. Dr. Ivanova, Dr. Brein, Prof. Lecolazet and others and related to vertical gravity gradient work by the Darmstadt Group, Prof. Gerstenecker etc, and others the new results are of great scientific and practical impact. They agree quite well with results found in Japan, GDR and in California.

Such research is especially important in view of the general goal of the group, i.e. to find out reliable techniques by which precise gravimetry can supplement other techniques (such as precise levelling etc) in monitoring plate tectonics and corresponding gravity variations as studied by SSG 3.40. (Prof. Boulanger), predict seismic events, monitor isostatic and other subsidence and uplift phenomena such as the Fennoscandian uplift, Japanese, Iranian, Californian and Sowjet earthquake premonitoring. HOWEVER, THE AIM OF THE SSG IS TO DEVELOP TECHNIQUES FOR SUCH STUDIES IT IS NOT THESE STUDIES THEMSELVES. The increasing importance of environmental (and similar) effects as well as of instrumental aspects with increasing accuracy of gravimetry makes such studies necessary. An other aspect where new techniques are still at their very beginning is gravimetry in combination with gradiometry, e.g., in moving vehicles in order to separate vehicle accelerations from gravity or supplement "horizontal" gradiometry in order to enable geodetic differential geometry with vertical gradients. The latter being much more dependent on shallow and transient density variations. In that connection precise gravimetry may indeed become a new and more reliable tool.

Some members, e.g. Dr. R.L. Forward (USA), were active in gravitational theory studies. Problems such as gravitational absorption might become of interest in the future in global high precision gravimetry; a study of that kind is in the beginning stage at Darmstadt after some suggestions by Prof. Treder/GDR.

Prof. Gerstenecker/F.R.G. has achieved precision of 0.2 microgal in laboratory vertical gravity gradient work. In field work corresponding accuracy is "destroyed" by environmental perturbations. Only in repeated measurements accuracy of ± 1 to 3 microgal is now feasible. To the extent that random variations are really separated from systematic effects a large number of repetitions thus yields accuracy of ± 200 nanogals or so, at least formally. But extreme care is necessary when talking on such accuracies because environmental effects amount to about $5 \cdot 10^3$ nanogals (atmospheric) and about $\pm 3 \cdot 10^4$ nanogals due to rainfall etc. Therefore, I do not want to reconfirm such accuracy. We have indeed to pay strong attention to transient phenomena and carefully take their implications into acount.

The use of repeated precise gravimetric measurements, in connection with volcanic activities and eruptions is presently tested by Prof. Torge, Dr. Coron and others.

The numerous Japanese activities in active seismic areas together with results found in other countries prove that precise gravimetry plays today a role in geophysics nobody has anticipated some years ago.

Continuous activities in the Sovjet Union in the field of high precision gravimetry (construction of a new pendulum apparatus and of a very precise free fall gravity apparatus) and collaboration with France and other countries render global highly precise gravity nets possible where the absolute reference is given by free fall absolute g-data and densification is repeatedly done by gravimeters.

As far as data handling techniques are concerned Strang van Hees, Bjerhammer and others advocate methods which will finally lead to a complete elimination of the geoid as a reference surface in time dependent geodesy; Bjerhammer has shown consequences in dealing with isostatic uplift in Scandinavia. Such ideas are basically initiated by Molodenskii. Numerical test computations by Groten and others in the Rhinegraben test net revealed that such considerations, i.e. the replacement of Δg by $\partial T/\partial r$ and of orthometric heights h by ellipsoidal heights H, are of small impact in most local Δg-interpretations but can be important in regional or global studies. In general, it seems to be worthwhile to use the ellipsoid (or the telluroid) as the reference in gravimetry.

The intricacy of second derivatives of potential is obvious when observed data are compared with $\Delta g \rightarrow \partial T/\partial x_i\ \partial x_j$ transforms. Smoothed (steady state) computed results seem to be superior.

Summarizing we can state: International cooperation in the field of precise gravimetry has reached a level and a variety of applications it never had before.

From the scientific viewpoint g-fields are really considered as time varying quantities implying completely new methods and, to some extent, new theories as stressed by Prof. Grafarend. The role of time varying environmental effects in gravimetry and the corresponding measurements and evaluation (and analysis) of such remarkable variations is more important than ever before.

It was shown during the time interval 1974-1978 that gravity in field work of relative accuracy $\pm 10^{-9}$ can be measured; corresponding tidal corrections have been made available; this accuracy holds for repeated observations. In stationary work $\pm 10^{-10}$ or even better is feasible over longer time intervals. The implications, such as linearity and periodic errors, stationarity of calibration factor, have been studied and have, however, further to be investigated and the possible new applications need to be studied in the future. E.g., in principle gravimetric monitoring (as combinations of field gravimetry, absolute gravity monitories, tide gauge monitoring and levelling) yields sufficient accuracy for studying: dilatancy vs. other pre-earthquake effect, plate subduction vs. plate collision etc, different types of subsidence and uplift related to water table variations (water table increase can imply gravity increase as well as decrease) depending on other circumstances. Similarly, at present a unique regression between atmospheric "lows" and "subs" has not yet been found. Therefore, also in this respect additional research is necessary. Similarly, the regression of gravity change with elevation changes varies from -0.3 μgal/cm to + 0.2 μgal/cm.

Details:

With modified model G and the new model D an accuracy of ± 3 microgal over distances of the order of 10 km is feasible now in a single (forth and back) measurement. Drift effects are reduced by a factor 10 or so according to recent research by C. Gerstenecker; drift with model D meters was, in general, found to be not as stable as was generally expected earlier, i.e. it is not 10 times higher than with model G meters as could be expected from 10 times higher resolution. But in the Rhinegraben testnet skillful operators achieved about twice lower drift than with G-meters. Precise gravimetry is still a matter of skillful handling. Therefore, members of a special group (Drs. L. Petterson, (chairman), A. Kiviniemi, R. Brein and C. Gerstenecker) elaborated a manual for precise gravimetry which should assist practitioners and newcomers. I express my sincere thanks to that working group.

Accuracy in gradiometry involves evidently similar problems as in gravimetry. Therefore, accuracy is still supposed to be of the order of ± 1 Eötvös Unit.

The environmental perturbations and the partly unknown sources again detected during studies in the Rhinegraben net: e.g., Dr. Kiviniemi found gravity changes of more than 20 microgal increasing linearly with time within several hours after heavy rainfall; no conventional model can explain such g-variations. To the knowledge of the chairman the following joint projects were and are undertaken, respectively:

1) Fennoscandian net (3 lines): Cooperation by groups from Helsinki, Oslo, Stockholm, Zürich, Darmstadt, Frankfurt,

2) Canada:
   NRC-group

3) California:
US-groups (NGS etc)

4) Japan: several networks
Japanese groups

5) Garm-testnet (UdSSR)
SU-groups

6) Central Asia:
Helsinki + 50 groups

7) Iran-net (planned for Dec. 1978)
Darmstadt-group.

8) Iceland net:
Hannover-group.

Besides these nets other joint projects were carefully observed using conventional methods, e.g.,

9) Aegaeis-net:
Hannover-group,

10) Rhinegraben:
Helsinki, Munich (TU), Darmstadt, Zürich, Frankfurt (IFAG), planned for fall '78)

11) GDR-Testnet:
GDR-CSSR-cooperation

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After this general report Prof. E. GROTEN gives lecture of :

PRECISE GRAVIMETRY IN THE RHINEGRABEN NET

by

K. DEICHL, E. GROTEN, H.G. KAHLE

A. KIVINIEMI, E. KLINGELE & B. WEICHEL

The aim of the high precision gravity measurements in the Rhinegraben testnet was to test what extent high precision gravimetry can be used to monito tectonic and other mass transfer and corresponding elevation variations. For that purpose a net of about 40 by 40 km extension and consisting of about 80 points in an area of tectonic interest was set up. Gravity observations were started with conventional accuracy of about ± 10 microgals in 1972/73 ; finally within half a decade, i.e. until 1978, relative accuracy of ± 1.3 microgal was achieved by improved techniques. However, the local variations of gravity were found to be of the order of ± 20 microgals up to a maximum of 40 microgals ; they are supposed to be a consequence of heavy rainfall etc.. and are of principal importance in holocene areas like the Rhinegraben itself. As a consequence in combination solutions (using data obtained over several years) and accuracy of about ± 3 to ± 4 microgals was achieved. The influence of such "physical" disturbances hampers the use of "gravimetric monitoring" of elevation variations with time even though "stationary" application of precise gravimetry to monitoring such environmental effects might become increasingly important.

The Rhinegraben area seems to be relatively stable. Using a regression coefficient of 0.1 mGal/m = 0.1 microgal/mm the accuracy of ± 1.3 microgal/mm even 0.5 cm would be detected. When the levelling results from 1938 to 1978 are considered together with the gravity results the following general conclusions seem to be justified : In the area covered by the present gravity net there is an average subsidence of 1 cm within 40 years i.e. 0.25 mm/year up to maximum of 1 mm/year. The main reason for this is obviously the lowering of the ground water table ; whether of not any tectonic movement or motion has an additional influence is completely unclear. The local variations up to 1 cm/year are caused by artificial effects (water works, industrial effects etc ; the best example is the Pfungstadt area).

Prof. I. NAKAGAWA presents a paper on :

AN ACCURACY OF SCALE CONSTANT OF LA-COSTE & ROMBERG GRAVIMETERS (MODEL G) REVEALED BY INTERNATIONAL AND DOMESTIC GRAVIMETRIC CONNECTIONS

by

I. NAKAGAWA, M. SATOMURA & T. SETO

In gravity measurements, a discrepancy among the scale constants of gravimeters used is one of the most important but inevitable problems, especially when a difference of gravity values among the measuring stations is large. After the data that were obtained by two sets of international gravimetric connections amounting to about 1.8 gals and 2.1 gals, respectively, and one set of domestic gravimetric connection amounting to about 1.6 gals in gravity differences were adjusted by referring to the IGSN 71, the following values of correction factor for scale constants of LaCoste & Romberg gravimeters G-29, G-118 and G-196 were determined.

For the gravimeter G-29 : $1.000663 - 0.000042 \; \Delta g_{obs.}$

For the gravimeter G-118 : $1.000215 - 0.000061 \; \Delta g_{obs.}$

For the gravimeter G-196 : $1.000640 + 0.000121 \; \Delta g_{obs.}$

Using these correction factors, the gravity value at each measuring station was re-calculated. The discrepancy between the value thus obtained and that of the IGSN 71 was almost less than $\pm$ 0.03 mGals at all stations.

Michel VAN RUYMBEKE reports on :

SENSITIVITY ADJUSTEMENT AND LEVELLING OF LACOSTE-ROMBERG GRAVIMETERS

A technique using the electronic output and a digital voltmeter during field measurements allows to work at constant sensitivity without depending upon level readings.

Dr. R.G. HIPKIN presents :

A MICROGRAVIMETRIC NETWORK FOR SECULAR GRAVITY STUDIES IN SCOTLAND

...

This paper reviews subsequent work extending the earlier tests on the drift characteristics of the LaCoste & Romberg gravimeter G-275, together with some preliminary results from field measurements carried out between 1976 and 1978. In a previous paper, I described the reasons for setting up a microgravimetric network in Scotland and its relation to the conflicting evidence of post-glacial uplift from precise levelling mareographic and geomorphological data.

Prof. Z. SZABO presents :

SOME REMARKS ABOUT THE PRECISION OF GRAVIMETER MEASUREMENTS

The complete text is reported at the end of the item (see p. I-E-15).

Dr. G. BOEDECKER presents :

INSTRUMENTAL INVESTIGATIONS AND IMPROVEMENTS OF LACOSTE-ROMBERG GRAVITY METERS

For the relative gravity measurements in the new gravity base net of the Federal Republic of Germany, LaCoste-Romberg gravity meters (mainly model G) have been used. The instruments were checked for the influence of battery-voltage, temperature, air pressure and magnetic field. The meters were improved by flat tripods containing more sensitive levels, batteries with constant voltage regulator and better foot screws. For the transport of the gravity meters, an air conditioned and spring suspended box has been utilized with good success. Furthermore an attempt was made to determine the fine structure of the calibration function by means of a tilt table, the tilt being determined through a laser interferometer.

The investigations showed again, that each gravity meter is an individual. The determination of coefficients for the influences of air pressure and temperature turned out to be somewhat difficult because of the irregular drift behaviour induced by the changing temperature or air pressure respectively.

Dr. C. GERSTENECKER reports on :

THE INFLUENCE OF AIR PRESSURE CHANGES ON PRECISE GRAVITY MEASUREMENTS

The analysis of residuals of earth-tide measurements demonstrate that air pressure changes influence the gravity value of any station directly. Estimations of this effect are given and computational methods for an air pressure correction are proposed. The proposed methods are tested on results obtained from high precision gravity measurements.

Dr. C. GERSTENECKER gives lecture of the paper :

ON THE APPLICATION AND ANALYSIS OF A SECOND ORDER DERIVATIVE OF THE DISTURBING POTENTIAL IN THE UPPER RHINEGRABEN

by

G.W. HEIN

Interpolation of deflections of the vertical and detailed geoïd computation were performed in the Upper Rhinegraben by using the second derivatives of the disturbing potential T_{xz}, T_{yz}, T_{xy}, $(T_{xx} - T_{yy})$ as obtained by torsion balance at approximately 6000 stations. The free-air gravity field calculated by numerical integration of the horizontal gradients was compared with the directly measured (free-air) gravity values. For the analysis as well as the separation of the quantity $(T_{xx} - T_{yy})$ a rigorous approach for computing all components of the anomalous part of the Eötvös tensor was developed taking into account the topography on the basis of Molodensky's theory.

Some remarks about the precision of gravimeter measurements

Z. Szabó

To investigate the secular variation of gravity it is essential to have a right judgement of the accuracy attainable with our instruments.

The analysis should be extended over the following aspects:

1./ the resolving power and the repeatibility of the instrument
2./ the instrumental effect of the external factors
3./ the gravity effect of the external factors

Many scientists have studied already the above mentioned problems so now we have a more or less clear picture about the magnitude of these effects. In spite of these facts our opinion is that when we are speaking about microgals we are overestimating the accuracy of our gravimeter measurements.

To obtain a realistic picture about the accuracy of the measurements we have analysed some practical cases.

From the high precision gravimeter measurements so far published we have chosen the data of Kiviniemi obtained on the Fennoscandian base line and those of Elstner's having obtained on the East-West base line in the German Democratic Republic.

Elstner and Kiviniemi did their best to achieve the possible utmost precision which could be attained by gravimeters.

Some other exemples from our measurements carried out on the Hungarian calibration line will be presented as well.

On the following tables we have presented the results of Elstner and Kiviniemi, in the last column can be seen the maximum deviation between the measurements carried out with the same instrument but in different years. The last row contains the maximum deviation between the measurements carried out by different instruments but in the same year. /Tables 1-6./

It has been expected that the deviation between the observations of different gravimeters would be higher than the others because of the possible systematic differences among the instruments. To our surprise the two deviations are of the same order, which means that we could not eliminate completely the effect of external factors i.e. our corrections are not reached the necessary precision.

The following tables seem to support this conclusion. We have listed some of Kiviniemi's corrected and uncorrected results. The corrections included: the reduction for different observation elevation, instrumental pressure correction, atmospheric correction, temperature correction and dial correction. It can be seen on the table that the maximum deviations and the standard errors are the same in the corrected and uncorrected cases as well. /Tables 7-9./

On the following table the results of Sharpe gravimeter measurements carried out on the Hungarian calibration line have been presented. The maximum deviations and the standard errors are indicated as well. /Table 10./

It is worth to mention that there are significant differences between the observations carried out in the spring and in the early winter. We attribute this phenomenon to the effect of the variation of the ground water table. In Hungary according to long series ground water level registrations the level is the highest in March, April and the lowest in November and December. Since the calibration line lies on an area covered by young sediments and the know ground water level fluctuations are of the order of 1-3 meters it is justified to attribute the observed differences to the ground water fluctuations.

Another aspect what we have to take into consideration in the accuracy investigations is that in gravimeter measurements the number of repetitions are normally less than 10 and we have to reach a probability of at least 0.99 to be sure that the given variation is a real one. In that case, depending on the number of repetitions, the confidence interval can be 3-4 times larger than the standard errors.

To complicate the problem, in case of long period variations the ageing of the instruments can result changes in the sensitivity of the gravimeters. The same type of instruments can have the same sensitivity changes so to verify a certain gravity variation we have to measure with different type of gravimeters. Using different gravimeters we can separate the instrumental effects from the real gravity variations.

As conclusion by the end of this short discussion we can state that a less than 50 μgal gravity variation measured by gravimeters cannot be considered a real variation. That means that to verify the existence or non existence of the secular gravity variation the application of absolute gravimeters promise earlier results than the use of relative instruments.

Potsdam-Woltersdorf

after Elstner et al

Gravimeter No.	1970	1971	1972	1973	1974	1975	/max - min/
	μgal						μgal
153	+2022.9						
198	+2032.8	+2037.7	+2034.2	+2029.1	+2044.4		15.3
207	+2026.2	+2023.9	+2033.3	+2030.9		+2038	14.1
208				+2031.5	+2042.1	+2047	15.5
209	+2029.8						
242		+2034.1	+2027.2				6.9
253	+2032.0		+2032.3			+2031	1.3
312					+2041.8	+2037	4.8
/max - min/	9.9	13.8	7.0	2.4	2.6	16	

Woltersdorf-Diedersdorf

153	+4415.2						
198	+4411.4	+4413.1	+4396.1	+4395.9	+4390.6		22.5
207	+4405.4	+4409.9	+4403.0	+4402.1		+4422	19.9
208				+4401.7	+4402.1	+4414	12.3
209	+4410.0						
242		+4409.9	+4400.8				9.1
253	+4418.6	+4413.0	+4394.4			+4370	48.6
312					+4405.1	+4378	27.1
/max - min/	13.2	3.2	8.6	6.2	14.5	52	

Table 1.

Irxleben-Detershagen
after Elstner et al

Gravimeter No.	1970	1971	1972	1973	1974	1975	/max - min/
	μgal						μgal
155	-5121.8						
198	-5140.6	-5142.4	-5142.1	-5135.4	-5136.0		7.0
207	-5126.5	-5142.9	-5143.7	-5135.6		-5157	30.5
208				-5137.1	-5147.7	-5155	17.9
209	-5130.3						
242		-5142.4	-5138.0				4.4
253	-5128.4	-5144.1	-5134.3			-5138	15.7
312					-5142.2	-5127	15.2
/max - min/	18.8	1.7	9.4	1.7	11.7	30	

Detershagen-Genthin

153	+557.3						
198	+563.7	+563.4	+567.2	+565.3	+555.4		11.8
207	+556.0	+569.1	+567.4	+564.2		+573	17.0
208				+565.5	+567.9	+557	10.9
209	+559.0						
242		+561.3	+561.3				0.0
253	+560.3	+564.4	+564.4			+584	23.7
312					+564.6	+554	10.6
/max - min/	7.7	7.8	6.1	1.3	12.5	30	

Genthin-Potsdam

153	+557.3						
198	+563.7	+563.4	+567.2	+565.3	+555.4		11.8
207	+556.0	+569.1	+567.4	+564.2		+573	17.0
208				+565.5	+567.9	+557	10.9
209	+559.0						
242		+561.3	+561.3				0.0
253	+560.3	+564.2	+564.4			+584	23.7
312					+564.6	+554	10.6
/max - min/	7.7	7.8	6.1	1.3	12.5	30	

Table 2.

Gravi-meter No.	I - D	D - G	G - P	P - W	W - D
	μgal				
174	-5152±12	+565±11	-2489±11	+2053±11	+4415±11
280	-5136±13	+593±13	-2464±14	+2039±13	+4374±13
198	-5127±9	+591±9	-2476±9	+2053±9	+4382±9
207	-5157±13	+573±13	-2440±13	+2038±13	+4422±13
208	-5155±10	+557±10	-2501±10	+2047±10	+4114±10
253	-5138±8	+584±8	-2470±8	+2031±8	+4370±8
312	-5127±14	+554±14	-2479±14	+2037±14	+4378±14
/max - min/	30	39	61	22	52

Table 3.

Vaasa-Joensuu
after Kiviniemi

Gravi-meter No.	1966	1967	1971	/max - min/
	μgal			μgal
24		$+119.1\pm28.7$		
55	$+131.7\pm6.2$	$+138.7\pm18.1$	$+119.3\pm6.1$	19.4
62	$+141.3\pm7.0$		$+122.2\pm4.1$	29.1
67	$+135.0\pm6.9$			
69	$+132.4\pm8.6$	$+134.8\pm20.4$		2.4
100			$+127.3\pm4.2$	
115		$+141.5\pm13.6$		
/max - min/	9.6	22.4	15.1	

Vaasa-Kramfors
after Kiviniemi

Gravi-meter No.	1967	1971	/max - min/
	μgal		μgal
24	$+480.3\pm12.0$		
55	$+491.5\pm6.6$	$+495.5\pm4.3$	4.0
62		$+483.6\pm4.4$	
69	$+483.8\pm5.1$		
100		$+495.4\pm2.2$	
/max - min/	11.2	11.9	

Table 4.

Vaasa-Äänekoski
after Kiviniemi

Gravimeter No.	1966	1967	1971	1972	1973	/max - min/
	μgal					μgal
24		+466.8±21.8				
55	+496.4±6.2	+487.5±13.8	+476.2±5.8	+487.5±6.4	+488.5±14.5	20.2
62	+487.9±7.0		+472.4±3.7	+489.4±4.2	+478.1±4.9	17.0
67	+487.3±6.9					
69	+495.7±8.6	+491.0±15.4				4.7
100			+476.4±4.1			
115		+494.5±10.4				
/max - min/	9.1	27.7	4.0	1.9	10.4	

Äänekoski-Joensuu
after Kiviniemi

Gravimeter No.	1966	1967	1971	/max - min/
	μgal			μgal
24		-347.7±21.8		
55	-364.7±6.2	-348.8±13.8	-357.0±5.5	15.9
62	-346.6±7.0		-360.2±3.9	13.6
67	-352.3±6.9			
69	-363.3±8.6	-356.2±13.7		7.1
100			-349.1±3.6	
115		-353.0±10.4		
/max - min/	18.1	8.5		

Table 5.

Gravi-meter No.	Vaasa-Aänekoski	Aänekoski-Joensuu	Vaasa-Kramfors	
	μgal			
55	+476.2±5.8	-357.0±5.5	+495.5±4.3	Kiviniemi
62	+472.4±3.7	-360.2±3.9	+483.6±4.4	
100	+476.4±4.1	-349.1±3.6	+495.4±2.2	
142	+508.5±9.2	-357.0±8.9	+499.3±11.1	Gerstenecker
258	+509.2±9.8	-380.0±9.4	+503.6±12.4	
/max - min/	36.8	30.9	20.0	

Table 6.

Vaasa - Kramfors

	N° 55 /1971/		N° 62 /1971/		N° 100 /1971/	
	Corrected	Uncorrected	Corrected	Uncorrected	Corrected	Uncorrected
	499.9	494.7	488.9	488.5	492.1	494.6
	509.9	503.5	471.5	474.1	504.1	503.5
	488.4	478.4	475.4	474.2	496.1	496.1
	503.9	498.6	452.7	451.0	494.8	490.9
	467.2	454.8	522.2	519.0	480.4	481.0
	476.5	470.3	462.0	461.4	494.8	492.6
	496.1	486.8	491.9	491.1	483.2	485.2
	489.9	481.8	470.6	467.7	489.7	485.3
max - min	42.7	48.7	69.5	68.0	23.7	22.5

Table 7.

Vaasa - Äänekoski

	N° 55 /1972/		N° 62 /1972/		N° 100 /1971/	
	Corrected	Uncorrected	Corrected	Uncorrected	Corrected	Uncorrected
	490.5	500.1	500.6	508.9	469.3	469.2
	488.4	497.1	467.9	473.9	468.2	471.9
	487.4	495.2	487.3	486.2	489.0	486.5
	510.9	517.1	498.9	498.9	487.2	480.1
	474.8	480.3	508.3	510.7	468.0	468.9
	471.8	479.3	492.5	493.5	485.9	485.0
	478.2	484.3	486.9	485.0	482.7	486.0
	502.0	507.7	492.5	492.9		
max - min	39.1	37.8	40.4	36.8	21.0	17.6

Table 8.

Vaasa - Kramfors

Instrument	Year	Corrected	Uncorrected
		Δg /μgal/	
No. 55	1971	491.5±5.0	483.6±5.7
No. 62	1971	479.4±7.6	478.4±7.4
No. 100	1971	491.9±2.7	491.2±2.5
/max - min/		12.5	12.8

Vaasa - Äänekoski

Instrument	Year	Corrected	Uncorrected
		Δg /μgal/	
No. 55	1972	488.0±4.7	495.1±4.7
No. 62	1972	491.9±4.3	493.8±4.4
No. 100	1971	478.6±3.6	478.2±3.0
/max - min/		13.3	16.9

Table 9.

SHARPE 181-G

Date	B - V	V - F	F - D	D - K	K - P
	μgal				
1973. 03.	192.6±4.0	20.8±7.4	477.7±3.2	618.4±0.4	
	182.2±6.2	20.0±4.2	483.8±4.3	605.4±7.5	
11.	171.8±1.8	19.3±7.2	490.0±4.9	592.4±0.8	
1974. 05.	166.6±8.0	5.8±4.4	502.0±4.8	592.5±6.5	
	173.2±7.4	15.7±6.7	514.4±13.2	616.0±16.2	
10.	179.8±13.2	25.6±7.7	526.8±26.8	639.4±20.8	266.3±18.5
1975. 02.	184.4±0.4	3.2±1.2	483.6±2.4	583.2±1.6	244.8±7.5
	193.1±5.1	26.7±13.6	481.8±3.0	602.6±12.1	230.7±9.0
12.	201.7±2.5	50.3±2.2	480.0±6.4	622.0±11.2	216.6±5.4
1976. 03.	193.8±2.1	4.8±3.1	510.0±3.6	589.2±8.4	244.4±3.3
	186.4±5.9	18.8±8.2	497.8±7.6	595.8±5.1	237.6±4.2
09.	179.0±9.6	32.6±1.8	485.6±5.8	602.4±0.1	230.8±1.0
max - min	35.1 19.9	47.1 11.0	49.1 32.6	56.2 20.2	49.7 6.9

Table 10.

References

/1./ Elstner, Cl et al: The results of high precision gravity measurements carried out on the W-E line of GDR between 1970-75. Manuscript Presented in Halle 1976.

/2./ Kiviniemi, A.: High precision measurements for studying the secular variation in gravity in Finnland.
Publication of the Finnish Geodetic Institute 1974. No. 78.

/3./ Olejnik, S.: Bearbeitung der Messungen auf der Gravimetrischen W-E - Linic der DDR 1975.
Manuscript Geodätischer Dienst der CSSR 1976.

LISTE des PUBLICATIONS
reçues au
BUREAU GRAVIMETRIQUE INTERNATIONAL
(Juillet à Décembre 1978)

CONCERNANT LES QUESTIONS DE PESANTEUR

LISTE des PUBLICATIONS

* 589 - MATHER R.S., C. RIZOS, B. HIRSCH & B.C. BARLOW - "An australian gravity data bank for sea surface topography determinations (AUSGAD 76)". from : School of Surveying, Univ. of New South Wales, UNISURV G.25, p. 54-84, Sydney, 1976.

Gravity data banks used in geodesy are usually in the form of free-air anomaly means. The data presently available have been shown to be inadequate for determinations of sea surface topography because of unacceptable levels of systematic error and as free-air anomalies are unsuitable (MATHER 1975). Gravity data for the Australian region are based on the homogeneous Isogal control network with elevations referred to the Australian Height Datum. In constructing a new gravity anomaly data bank (AUSGAD 76), observed gravity values have been adjusted to absolute datum and scale. The data is then reduced to gravity anomalies for the Earth-telluroid system using the free net adjustment of the Australian levelling survey provided by the Division of National Mapping, Canberra, and the geopotential network for Australia prepared by MITCHELL (1972). The datum level surface adopted for Australia on the recommendation of the Division of National Mapping, is the tide gauge zero at Jervis Bay. All latitudes used in the computation of normal gravity were converted to a geocentric ellipsoid consistent with Geodetic Reference System 1967 (GRS 67).

The observed gravity values in AUSGAD 76 are based on the datum and scale adopted for Australia by BOULANGER et al. (1973). Datum is the International Gravity Standardisation Net 1971 (IGSN 71) value at the new National Gravity Base Station Sydney A. The scale is based on measurements using Soviet GAG2 gravity meters in 1973. It is considered to be more accurate than that established by IGSN 71 values in Australia and differs from the latter by 15 parts in 10^5. Measurements using Soviet pendulums in 1974 (GUSEV 1975) differed from the adopted scale by 2 ($\pm$ 2 parts in 10^5).

Error propagation patterns in both the gravity control network and the levelling survey, as determined from the internal statistics of the networks, indicate that effects with amplitudes around 0.15 mGal and estimated wavelengths of 7 x 10^3 km could contaminate AUSGAD 76.

Improvements to the present data bank are necessary to meet the requirements for use in determinations of sea surface topography with a resolution of $\pm$ 10 cm. It would be desirable to provide absolute gravity control of the Isogal network to $\pm$ 20 μgal at 10^3 km intervals, and introduce supplementary control for the Australian levelling survey by satellite position fixes in Central Australia as part of a 10 cm global system.

590 - SCHOOL of SURVEYING, Univ. of New South Wales. "Crustal motion studies in Australia and Papua New Guinea - Report to the International Centre for Recent Crustal Movements, Praha". from : UNISURV G.25, p. 109-120, Sydney, 1976.

* Les numéros font suite à ceux indiqués dans le Bull. Inf. N° 43, Novembre 1978.

593 - MATHER R.S. - "On the realization of a system of reference in four dimensions for ocean dynamics".
The Dept of Geodesy, Univ. of New South Wales, Sydney., 26 p,
Typewritten text presented at Colloquium on Radio Ocean. Hamburg, 29 Sept.- 6 Oct. 1976.

The determination of the instantaneous position of the sea surface from satellites can be related in principle to an absolute frame of reference in four dimensions. A basis therefore exists for referring variations in sea surface topography, irrespective of Earth space location, to such a system of reference when used in dynamic equations which apply at the air/sea interface. Such data can be evaluated in both deep oceans and on continental shelves without recourse to subjective judgements on the characteristics of ocean dynamics. In practice, the realization of such a system of reference is only as good as the tracking data used in maintaining geodetic concepts.

A major problem in the determination of sea surface topography as a global field is likely to be the establishment of tracking coverage with adequate precision in high latitudes. Surface gravity data could be used to improve orbits in regions where no direct tracking is available but only at the 1-2 m level, due to the data being sampled in relation to the sea surface and not the geoïd. It will not be possible to determine sea surface topography with wavelengths less than about 10^3 km in the absence of measurements of higher derivatives of the gravity field on a global basis.

As variations in sea surface topography which are not of tidal origin, have significantly smaller magnitudes than the sea surface topography itself, it follows that a proportionate improvement in the tracking resolution would have to precede the unambiguous detection of such variations without restriction of wavelength. Four dimensional concepts are also essential for the resolution of the tidal signal from the satellite altimetry data.

The application of principles underlying four dimensional geodesy to ocean dynamics in the context of a cohesive satellite altimetry program therefore constitutes a necessary basis for the synoptic monitoring of the air/sea interface.

595 - MUTTER J.C. - "The Queensland Plateau".
B.M.R., Geol. & Geophys., Bull. N° 179, 55 p, Canberra, 1977.

The Queensland Plateau is a large block of submerged continental crust embedded in the continental margin of northeast Queensland. The Plateau and its bounding troughs (Queensland and Townsville) were surveyed in 1971 by Compagnie Générale de Géophysique under contract to the Bureau of Mineral Resources. Seismic reflection profiling, gravity and magnetic sensing, and bathymetric profiling were conducted on a systematic grid of traverse lines. One of the lines approaches very closely a Deep Sea Drilling Project hole drilled on the outer edge of the Plateau.

With an evolutionary model for the Queensland Plateau determined, a complete history of plateau and basin evolution is proposed by relating the Plateau evolution to that of the adjoining Coral Sea Basin using results from Deep Sea Drilling Project drilling in the Basin. The model is then compared with Falvey's (1974) model of Atlantic continental margin formation and a significant departure is demonstrated. No rift-valley stage appears to have preceeded continent break-up and ocean formation. This is explained by using two lithospheric thermal anomalies, one in the Late Cretaceous and one in the Palaeocene-Eocene, and by suggesting rapid rifting of the Coral Sea Basin associated with the younger heat source.

596 - BRANSON J.C., F.J. MOSS & F.J. TAYLOR - "Deep reflection seismic test survey, Mildura, Victoria and Broken Hill, N.S.W.".
B.M.R., Geol. & Geophys., Rep. N° 183, 30 p, Canberra, 1976.

Techniques for recording deep crustal reflections were developed during an experimental seismic survey at Mildura, Victoria, and Broken Hill, NSW, during September to December 1968. The survey was carried out preparatory to a seismic reflection survey on the "Geotraverse" project, which was began by the Australian Upper Mantle Committee to study the Earth's crust and upper mantle along a line across the Precambrian shield in Western Australia.

Noise tests, expanded reflection spreads, and continuous reflection profiles mutually at right-angles.

Reflection data from the expanded spreads were analysed to provide velocity and depth estimates to reflecting horizons. Notwithstanding the inherent inaccuracies in timing the reflection events and in the method of analysing the expended-spread data, the seismic reflection results indicate a possible model of the structure of the crust and upper mantle at Mildura and Broken Hill. The crust, relative to sea level, appears to thicken from about 31 km at Mildura to about 36 km at Broken Hill. An intermediate layer, with an interval velocity of about 7.0 km/s, is at depths of about 23 km and 15 km in the two areas, respectively. In the crust above, the average vertical velocity is about 6.1 and 5.9 km/s at Mildura and Broken Hill, respectively. There is also evidence of shallow layering in the crust at Broken Hill at depths of about 7.1 and 10.5 km. A velocity reversal is evident at the latter depth, with a velocity of about 5.8 km/s in the layer immediately below on of 6.5 km/s.

The difference in the gravity effect between the two areas, obtained from a comparison of the proposed crustal columns, is in reasonable agreement with the difference in observed free-air anomalies at the Mildura and Broken Hill pendulum stations.

597 - MATHUR S.P., F.J. MOSS & J.C. BRANSON - "Seismic and gravity investigations along the Geotraverse, Western Australia, 1969".
B.M.R., Geol. & Geophys., Rep. N° 191, 63 p, Canberra, 1977.

On the recommendation of the Australian Upper Mantle Committee, the Bureau of Mineral Resources carried out a seismic survey across the Precambrian shield in southwestern Australia between June and December 1969. Deep crustal reflection and refraction information was obtained from explosions set off in five areas along the Geotraverse, a line extending from Perth through Coolgardie in the east to Point Culver in the southeast. The results have been combined with those from gravity surveys and from other seismic refraction surveys in southwestern Australia to obtain an integrated interpretation of the structure and composition of the crust and upper mantle.

The analysis of the seismic data indicates that the crust is of normal continental type in the east but changes towards the Perth Basin in the west. Near Kalgoorlie it consists of two layers with velocities of 6.12 and 6.66 km/s and is 34 km thick, whereas near Perth, close to the continental margin, it is 44 km thick and includes an extra basal layer of velocity 7.42 km/s, which thins out towards the east and southeast. The upper two crustal layers near Perth, on the other hand, thicken to the east and southeast. In the Perth Basin, about 7.5 km of sediments overlies a block of the crust which has been thrown down to the west along the Darling Fault.

Southeast of Coolgardie, the high-velocity basal layer is shown to be thin and the southeastern part of the crustal block has been upthrust to the northwest along the Fraser Fault. The measured velocity of the upper mantle underneath the abnormal crust is 8.25 km/s.

The seismically determined structure is consistent with a crust in or close to isostatic equilibrium, and with the observed gravity anomaly field in southwestern Australia for two possible density models of the crust and upper mantle. One of the density models is also consistent with the hypothesis that the high-velocity basal layer in the crust is garnet-granulite overlying eclogitic mantle.

598 - KERN G. - "Le prolongement du champ de pesanteur vers le bas : Etude mathématique et application au Fossé Rhénan méridional".
I.P.G., Mémoire Dipl. Ing. Géophys., 82 p, Strasbourg, 1971.

Etude de diverses formules de prolongement du champ vers le bas.
Expérimentation de diverses méthodes sur les résultats gravimétriques de l'extrémité méridionale du Fossé Rhénan, une région particulièrement intéressante du point de vue tectonique ou le fossé semble s'arrêter contre les premiers plis du Jura et amorcer une transition vers le Golfe de Montbéliard et la Bresse. Cette région est d'autre part suffisamment vaste pour permettre des calculs significatifs.

599 - GUZMAN P.A. - "Gravity survey in the Republic of El Salvador".
Inst. Geogr. Nac., Minister of Publications, 71 p, 1940.

Liste des résultats gravimétriques .
Anomalies à l'air libre et Bouguer, 1093 points.

600 - SWAIN C.J. & M. AFTAB KHAN - "Gravity measurements in Kenya".
from : Geophys. J. R. Astr. Soc., v.53, p. 427-429, 1978.

A new catalogue of gravity data from Kenya has been prepared and is briefly described here. New Bouguer anomaly maps have also been compiled and a copy is included.

601 - RIAD S. - "Shear zones in North Egypt interpreted from gravity data".
from : Geophys., v. 42, n° 6, p. 1207-1214, 1977.

The Bouguer anomaly map for the northern part of Egypt was used for determining fault systems which are probably present in the area. These systems show the presence of a number of almost parallel shear zones, striking in a northwest-southeast direction. Extrapolation of some of these zones is suggested in the Gulf of Suez area. The movement of the eastern side of each zone is thought to be right-lateral to the southeast. The shear zones are probably related to the interaction between the European and African plates. They probably started developing in the Oligocene and are presently still active. The opening of the Gulf of Suez is thought to be mainly due to the action of these transcurrent faults.

602 - SOFFEL H., K. PETERS & J. POHL - "Interpretation of a gravity profile across the southern part of the Hon Graben, Libya".
from : J. Geophys., v. 41, N° 5, p. 491-499, 1975.

A 90 km long profile with 251 gravity stations was measured across the southern part of the Hon Graben. From a combination of a previously published ΔT anomaly (SCHULT, 1974) and the Bouguer anomaly Δg", both measured along the same profile, a probable density structure for the southern part of the Hon Graben has been derived. The models show a sharp increase of thickness of Upper Cretaceous and Tertiary sediments at the graben borders. The thickness of 1800 m of these sediments, which has been obtained from geological observations, is compatible with the gravity models assuming a density contrast of 0.2 g/cm3 with respect to older sediments. In the central part of the graben a rise of the Pre Upper Cretaceous rocks, reaching up to about 300 m below the surface, divides the Hon Graben, at least in the southern part, into two separate troughs. In the western part of the graben border basic intrusions seem to exist, which are probably connected with the adjacent Jebel Soda volcanism.

603 - SIMPSON E.S.W. & A. du PLESSIS - "Bathymetric, magnetic and gravity data from the continental margin of southwestern Africa".
from : Canadian J. Earth Sci., v. 5, N° 4, p. 1119-1123, 1968.

The morphology of the continental margin between Cape Town (34°S) and Walvis Bay (23°S) is characterized by a broad, terraced shelf, separated from the slope by a poorly defined shelf break which deepens northward. A major belt of positive magnetic anomalies follows the upper slope, but is displaced in a right-lateral sense on to the continental shelf at 31°S, to the north of which it crosses a bend in the shelf break and again follows the upper slope. The gravity data is consistent with the normal edge effect associated with an isostatically compensated continental margin.

604 - SCRUTTON R.A. - "Gravity results from the continental margin of south-western Africa".
from : Marine Geophys. Res., v. 2, N° 1, p. 11-21, 1973.

Gravity, magnetic and bathymetric data were collected over the continental margin of south-western Africa by H.M.S. "Hecla" in 1966. A study of the gravity measurements shows that the positive free-air anomalies of the continental edge effect are unusually large, and in excess of those calculated for an isostatic model of the Earth's crust. Taking into account the available seismic and magnetic evidence, a two-dimensional crustal model has been designed incorporating a body of relatively high density in the upper crust to account for the unusually large values.

605 - MOHR P.A. & P. GOUIN - "Gravity traverses in Ethiopia".
Haïlé Sellassie I Univ., Geophys. Obs., Bull. N° 10, Addis-Ababa, 1967.

New gravity traverses have been made and are described in this paper and shown on a map.

The opportunity is also taken to describe and discuss some major geological structures observed along some of these traverses.

606 - LE MASNE D. - "Mesures gravimétriques en Pays Basque et Béarn (Anomalie du Labourd)".
Acad. Montpellier, USTL, DEA Tectonophys. 23 p, 1977.

Etude de l'anomalie gravimétrique du Labourd, du nom que les géophysiciens et les géologues ont l'habitude de lui donner, qui recouvre en fait bien plus que la province basque du Labourd. L'anomalie est même maximale au Nord de la Soule (Mauléon, Tholdy), autre province basque.

Le cadre des mesures est approximativement un rectangle de 110 km d'Est en Ouest sur 60 km du Nord au Sud.

607 - GAUYAU F. - "Etude géophysique dans le Levant espagnol (entre Alicante et Totana) : le problème du prolongement de l'accident d'Alhama de Murcia".
Acad. Montpellier, USTL, Thèse Dr. Sci. de la Terre, Géol. Appliquée, 114 p, 1977.

Le travail présenté ici est le résultat d'une campagne de mesures gravimétriques et de sondages électriques qui s'est déroulée du 12.09 au 10.11.1975 dans le Levant espagnol (provinces d'Alicante et de Murcia).

Cette campagne avait pour but de mettre en évidence le prolongement éventuel d'un grand accident NE-SW qui s'étend sur 100 km de Huercal Overa à Murcia, au sein des cordillères bétiques : l'accident d'Alhama de Murcia ; cet accident visible dans les terrains néogènes, se perd en effet à l'Est de Murcia.

L'étude géophysique recouvre la région de Murcia ainsi que la région s'étendant à l'Est de cette ville jusqu'à Alicante.

Avant d'exposer les résultats de cette campagne, nous présenterons d'abord la géologie et l'histoire tectonique récente de ce secteur.

608 - BAYER M. - "Etude gravimétrique de la Corse".
Acad. Montpellier, USTL, Thèse Dr. Sci. de la Terre, Géol. Appliquée, 131 p, 1977.

Environ 700 observations ont été effectuées au cours des deux campagnes gravimétriques en 1973 et 1975.

Différentes méthodes ont été utilisées pour l'interprétation des anomalies gravimétriques et différentes cartes sont présentées :

Carte de l'anomalie régionale (Polynomes)
" de l'anomalie de Bouguer prolongée à 6 km
" du gradient vertical, de la dérivée seconde
" des anomalies magnétiques.

609 - BOURMATTE A. - "Etude gravimétrique du Tanezrouft (Algérie)".
Acad. Montpellier, USTL, Thèse Dr. 3ème cycle Géol. Appl., Tectonophys., 139 p, 1977.

Le travail que nous présentons ici constitue le résultat des levés gravimétriques effectués de novembre 1974 à mars 1975 dans le Tanezrouft (Algérie). Nous avons adjoint aux résultats de cette mission ceux obtenus par la mission 1971-1972 dans le Tanezrouft oriental organisé par le Centre de Recherche sur les Zones Arides, l'IMPGA et l'ORSTOM (J. RECHENMANN, 1973).

L'ensemble des deux levés totalise plus de 4.700 points (2000 pour la première mission et 2700 pour la seconde) et couvre une surface de près de 17 degrés carrés, soit plus de 200 000km². Les stations (plus de 276 par degré carré) sont réparties sur plus d'une vingtaine de profils Est-Ouest espacés de 18 km. Le pas de mesure sur chaque profil est de 3 km.

L'examen des cartes d'anomalies gravimétriques confirme l'opposition entre deux domaines géologiques différents :

- Le craton ouest africain, stable depuis 2000 Ma, présente des anomalies étendues et de faible amplitude, pouvant caractériser des variations de profondeur du socle sous une couverture sédimentaire relativement mince. A l'Ouest de la carte, nous avons hésité à lier l'origine des grosses anomalies au grand bassin de Taoudeni dont la bordure Nord-Est aurait alors été marquée par un important accident SSE-NNW.
- La chaîne panafricaine, d'âge 600 Ma, présente des anomalies mieux marquées, allongées et de direction générale Nord-Sud. Nous avons pû souvent les corréler avec la géologie de surface, même si les masses apparentes sont parfois insuffisantes pour expliquer des anomalies importantes.

610 - HUSTI G.J. - "Deviations of the vertical in the Netherlands from geodetic astronomical observations".
Netherlands Geod. Comm., Pub. Geod., v. 6, n° 3, 45 p, Delft, 1978.

611 - DUCARME B. & P. MELCHIOR - "A trans-world tidal gravity profile".
Obs. Royal de Belgique, Comm. Sér. A, N° 48, Sér. Géophys. N° 132, Bruxelles.
from : Physics of the Earth & Planetary interiors, v. 16, n° 3, p. 257-276, 1978.

Tidal recordings have been made with high-precision equipment at twenty-eight stations in the South East Asia and the South Pacific areas. Each station was occupied for five months or more. Amplitude factors (δ) and phase differences (α) of the principal tidal constituents exhibit a regional behaviour which results from the oceanic-tide interaction. At Alice Springs, Northern Territory, the middle point of Australia, the results based upon nine month's observations fit fairly well the Molodensky theory on the dynamical effects of the liquid core of the Earth.

612 - MONKA, W. TORGE, G. WEBER & H.G. WENZEL - "Gravimetric, altimetric and astrogeodetic geoid determinations in the North Sea region".
Wissens. Arbeiten der Lehrst. für Geod., Photog. & Kartog. an der Technis. Univ. Hannover, N° 80, 41 S, 1978.

In this paper three geoid determinations based on different observations (gravity anomalies, GEOS-3 altimeter measurements and astro-geodetic vertical deflections) are presented. All three geoids refer to the mean earth ellipsoid, therefore comparisons between the geoids can be made. The rms differences between gravimetric and altimeter geoid are approximately ± 0.2 m, while the rms differences between gravimetric and astrogeodetic geoid vary between ± 0.5 m and ± 1.4 m.

613 - GAIBAR-PUERTAS C. - "El campo de pesantez y la estructura geologica del estrecho de Gibraltar".
Inst. Geogr. y Catas., 85 p, Madrid, 1973.

This contribution to the "Geodynamics Project" consists in the analysis of the distribution of the gravity anomalies Faye (free-air) and Bouguer (corrective) using the values obtained in 208 points in the Strait of Gibraltar, this evidence of the logical and relative parallelism between the track of the isogams Faye and Bouguer.

In this sector it was known that the gravity deficit ascribed to the Gibraltar Arc drawing an arching band of 120 km. wide crossing from N. to S. of the Strait of Gibraltar.

Our fields of isogams reveal that in the submarine substratum of the Strait that arc of negative gravity anomalies presents a sudden traverse expansion that, really, constitutes a second negative band oriented towards the length of the Strait. With a width of 50 km. and an approximate length of 260 km. this new band of negative anomalies extends from the meridian of - 7°20' to the E. 15°N. Inside it, the negative anomalies show the maximum intensities of - 147 mGals (Faye) and - 121 mGals (Bouguer) in the sector of Ceuta. These values are similar to the more important minimum shown by the gravity in the Spanish Betic-cordilleran of the alpidic range (Mulhacén = - 139, Granada = - 132 and Capileira = - 71 mGals) and, of course, with the known oceanic bands of negative gravity anomalies because their maximum intensity oscilates between - 100 and - 200 mGals.

Inside this new oceanic band of negative anomalies show from 8 minimums that appear to define three geostructural directions approximate to the orientation of the arrow of the Gibraltar Arc : a-b according to W. 10°S.- E. 10°N., E-F orientated according to W. 05°S. - E. 05°N. and A-B-C-D (benk in the form of a trapeze enfolding the border of the most northerly part or Africa) in which the central and most extensive segment (B-C), orientated according to W.-E, establishes the most important minimums. Cutting almost perpendicularly the Gibraltar Arc, these geo-structural directions correspond to the most recent folding phases. ...

614 - KAHLE H.G., M. CHAPMAN & M. TALWANI - "Detailed 1° x 1° gravimetric Indian Ocean geoid and comparison with GEOS-3 radar altimeter geoid profiles".
from : Geophys. J. R. Astr. Soc., n° 55, p. 703-720, 1978.

A new set of 1° x 1° mean free-air anomalies in the Indian Ocean is determined on the basis of previously published free-air anomaly maps (Talwani & Kahle) and the most recent Lamont surface ship gravity measurements. The data are then used to compute a (total 1° x 1° gravimetric Indian Ocean geoid. The computation is carried out by combining the Goddard Space Flight Center (GSFC) GEM-6 geoid and a difference geoid that corresponds to the differences between the set of 1° x 1° surface gravity values and the GEM-6 gravity anomalies. The difference geoid is highest over the Madagascar Ridge (+ 20 m) and lowest over the Timor Trough (- 30m). The total geoid is compared with GEOS-3 radar altimeter derived geoid profiles and geophysical implications are discussed.