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GEODETIC GRAVIMETRY IN THE USSR

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Series A

Reports on the Problem of Soviet Capabilities
in Geodesy, Cartography, Photogrammetry, etc.

Number 1

GEODETIC GRAVIMETRY IN THE USSR
(CIA/RR ER-1)

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18 October 1951

(CIA Project ORR 63-51)

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S E C R E T

FOREWORD

This publication, "Geodetic Gravimetry in the USSR," issued as ORR External Research Study, Number 1 (CIA/RR ER-1), represents the initial report originating from the project entitled "The Problem of Soviet Capabilities in Geodesy and Cartography" (CIA Project ORR 63-51). The proje25X1A5a1ng carried out for the Office of Research and Reports, CIA, [redacted]

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The ultimate objective of the project is to provide a systematic analysis of Soviet capabilities in geodesy and cartography in their relation to the current and future military requirements of the USSR and to determine whether the Soviet Union possesses any advantages over the United States in scientific and organizational resources in the fields concerned.

For publication in the External Research Study series, individual reports originating from this project will be divided into two groups, as follows:

Series A: Reports on geodesy, cartography, photogrammetry, etc., pertaining to the main subject of the project.

Series B: Intelligence notes on geophysics, oceanography, aerology, etc., consisting of significant materials and information on developments, trends, and new theories and techniques uncovered in the course of research on the main subject of the project.

S E C R E T

CONTENTS

Appendixes

Maps

REPORT NO. A 1

GEODETIC GRAVIMETRY IN THE U.S.S.R.

The term "geodetic gravimetry" was introduced by the Russian geodesists. It means the application of gravimetric data to problems of geodesy. It may be said that this application is essentially a Russian development, although both the theoretical foundation and even some practical applications of this method can be found in the works of geodesists of many countries, such as Stokes, Poincare, Helmert, Vening Meinesz, de Graaf Hunter, Heiskanen and others. Among the Russian geodesists F. N. Krasovskiy, J.A. Kazanskiy, B.V. Dubovskoy and M.S. Molodenskiy have been especially active in this field. The latter gives the most complete exposition of the method in his monograph, "Basic Problems of Geodetic Gravimetry" ("Osnovnyye Voprosy Geodezicheskoy Gravimetrii", Trudy Ts.N.I.I.G.A.i.K.,Vyp. 42, 1945). In his paper reasons for the development of this branch of geodesy in the U.S.S.R. are indicated as follows:

(1) Availability of a systematic gravity survey of the U.S.S.R. which began in 1932.

(2) The great expanse of the country which makes impossible its thorough geodetic coverage by old conventional methods.

(3) The urgent need of cartography for regions only recently settled and not connected with main geodetic arcs.

In regard to these statements we should note that the gravity survey is but one of the numerous systematic surveys of the territory, such as magnetic, water resources, mineral resources, etc., initiated in 1932 by the Council of Labor and Defense (Sovet Truda i Oborony).

According to B. N. Rabinovich (Osnovy Postroyeniya Opornykh Geodezicheskikh Setey, 1948), the geodetic basis for cartographic work in the U.S.S.R. covers 11,000,000 sq. kilometers, or somewhat less than 50 percent of the territory. Considering that the geodetic network in European Russia and Central Asia is much denser than in Siberia we may assume that the geodetic coverage in Siberia does not extend for more than 40 percent of its territory. In fact, north of latitude 55° only detached triangulations of low order along the Arctic Coast are known to exist. The main Siberian network has only three considerable extensions, one along the Yenisey River northward to the city of Yeniseysk, another along the Lena River to about Olekminsk and another along the Okhotsk Seacoast. The remainder of the territory is dotted with astronomical and gravity determinations. In the opinion of Russian geodesists, the combined use of these two types of data provides the necessary control for cartographic uses. The purpose of this report is:

(a) to give the present status of our knowledge of Russian gravimetry and astronomic determinations.

(b) to ascertain what Russian material is available.

(c) to ascertain what Russian material is in existence and what material is of sufficient importance to warrant a systematic search for it.

The amount of Russian material covering these subjects is enormous. On the subject of gravity along a bibliography has been collected of 309 items actually found and examined amounting to over 6,000 pages. This is, of course, an incomplete list, as many papers are known to have been published but are not yet located. A thorough coverage of Russian gravimetry would undoubtedly include at least 400 papers, comprising some 8,000 or more pages.

STATUS OF GRAVIMETRIC SURVEY

The beginning of a systematic gravity survey in the U.S.S.R. was made in 1932. In the spring of that year the Gosplan (the main agency of planning) called a geologic-geodetic conference which adopted a resolution to obtain at least one pendulum gravity measure per each 1,000 sq. klm. of territory or roughly 23,000 measures for the U.S.S.R. This resolution was approved by the government on September 20, 1932. The supervision of this as well as of all geodetic work, was given to an organization directly under the jurisdiction of the Council of Ministers. The present name of this organization is Glavnoye Upravleniye Geodezii i Kartografii (Main Directorate of Geodesy and Cartography).

How successful have the Russian gravimetrists been in putting this resolution into effect? Molodenskiy anf Fedynskiy (Izv. Ak. Nauk, Ser. Geol. i Geof. Vol. 11, 1947, pp. 395-408) state that by 1947 a territory of 15 mill. sq. klm. has been uniformly covered by 15,000 measures.

From this figure, and the figures given for the catalogues of 1933 and 1938 (see below) we find the annual rate of accumulation of gravimetric data to be 1,500 for the period of 1933-38, and 650 for the period 1938-47. The latter figure undoubtedly reflects war conditions, although gravity and magnetic surveys continued uninterruptedly even during the worst period of the war. Accepting the lower figure as the annual rate of production for the period 1947-51, we estimate that as of the beginning of the year 1951, some 18,500 pendulum measures were available for the whole territory of the U.S.S.R., by accepting the latter higher figure, 21,000 measures. The time true value probably lies between these two figures.

The same authors give a detailed description of the progress of this survey. They distinguish the following periods in Russian gravimetry:

(1) Before 1932. Measures without any general plan, much poor work, lack of experts and technical personnel. Data mostly from Ural, Caucasus and European Russia. Complete dependence on foreign instrumentation.

(2) 1932-1938. Center of field gravimetric work moving eastward into Kazakhstan, Western Siberia and the Arctic. Extensive training of new personnel. Definite plan of survey. Construction of instruments.

(3) 1938-1947. Intensive measurement program in Eastern Siberia, in newly acquired territories in the West and in the Arctic. Revision of previous determinations. Complete independence of foreign instrumentation.

All gravimetric determinations in Russia are now divided into four classes:

- I class - mean error less than 1 mlg.
- II class - mean error between 1 and 2 mlg.
- III class - mean error between 2 and 3 mlg.
- IV class - mean error greater than 3 mlg.

Sudakov (Geodezist, 1940, No. 11, pp. 5-12) in his article on the status of gravimetry in 1940 gives the following detailed data for the number of pendulum determinations of different precision:

Class	Before 1917	1917-25	1926-32	1933	1934	1935	1936	1937	1938	1939	Total
I	-	-	-	-	-	-	-	-	2	2	4
II	-	-	-	-	-	-	-	-	25	45	70
III	3	8	130	121	85	166	380	231	383	583	2090
Error 3-5 mlg.	170	63	630	444	496	623	1088	1288	-	-	4802
Error 5-7 mlg.	49	-	340	183	491	252	284	322	-	-	1922
Error 8-10 mlg.	14	-	53	16	116	37	35	49	-	-	320
No est.avail.	188	75	837	117	35	226	138	354	-	-	1970
Total by year	424	146	1990	881	1223	1305	1925	2244	410	630	11178

The gradual increase in precision is very strikingly portrayed in this table. At the present time the following five first class stations are considered fundamental and all field measures are based on one of them (Potsdam system):

Moscow	981559.0 ± 0.74 mlg.	(Sternberg Astr. Inst.)
Pulkovo	981900.5 ± 0.54 mlg.	(Astr. Observatory)
Kazan'	981558.7 ± 0.68 mlg.	(Univ. Astr. Obs.)
Poltava	981006.4 ± 0.67 mlg.	(Gravimetric Observatory)
Tbilisi	980177.7 ± 0.90 mlg.	(Geophysical Institute)

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Very thorough work was done by Pariyskiy and others in evaluating the gravimetric measures for these stations and reducing them to the Potsdam System.

There are also a number of other first-class stations which have been determined recently. The following have come to my attention:

Moscow	981546.8 ± 0.75 mlg.	(Grav. Lab. of Geoph. Inst.)
Leningrad	981930.8 ± 0.58 mlg.	(Institute of Metrology)
Kiyev	981072.3 ± 0.78 mlg.	(Astron. Observatory)
Obi-Garm	979536.3 ± 0.78 mlg.	(Seismol. Station, 38°43' N, 69°42' E).

The following first-class stations have been established in Siberia but no precise data on them are yet available.

Novo-Sibirsk

Khabarovsk

Yakutsk

Irkutsk

Of especial interest are gravity measures made in submarines in the seas, (Black, Okhotsk, Caspian, Japan), on the ice of large lakes like Baykal, and on drifting vessels and ice-floes in the Arctic. According to Mikhaylov (Sbornik NTiPS, Vyp. 5, 1944, pp. 49-59) by 1944 over 450 measures of this sort had been made.

AGENCIES PERFORMING GRAVITY WORK

There is a very large number of organizations in the U.S.S.R. connected with gravity work, either in actual surveying or in theoretical and instrumental development. The following list includes the most important agencies:

(1) Glavnoye Upravleniye Geodezii i Kartografii (Main Directorate of Geodesy and Cartography, abbreviation GUGK), present head S.G. Sudakov. General supervision of all gravimetric work done by any agency, as well as field work, construction of instruments, and theoretical development.

(2) Glavnaya Astronomicheskaya Observatoriya v Pulkovo (Main Astronomical Observatory at Pulkovo). Not much field work at present but its director, A. Mikhaylov, is one of the foremost gravimetrists in Russia.

(3) Tsentral'nyy Nauchno-Issledovatel'skiy Institut Geodezii i Kartografii (Central Research Institute of Geodesy and Cartography, abbreviation TsNIIGiK), very active. Its present head, A.S. Tatev'yan, appears to be a political nominee.

(4) Moskovskoye Aerogeodezicheskoye Predpriyatiye (Moscow Aerogeodetic Establishment, directly under 1, above).

(5) Soyuznyy Geofizicheskiy Trest (Union Geophysical Trust), mostly gravimetric surveys for oil (P. A. Pospelov).

(6) Glavnoye Geofizicheskoye Upravleniye (Main Geophysical Office in the Ministry of Geology): N. M. Stupak.

(7) Geofizicheskaya Sluzhba Uglerazvedki (Geophysical Service of Coal Prospecting): A.A. Devyatkin.

(8) Institut Geofiziki (Institute of Geophysics at the Ac.Sc., U.S.S.R., a merger of two former Institutes of Theoretical Geophysics and of Seismology), Director, O. Y. Shmidt, very active in theoretical anf field work.

(9) Nauchno-Issledovatel'skiy Institut Prikladnoy Geofiziki (Research Institute of Applied Geophysics): V.V. Fedynskiy, very active.

(10) Vsesoyuznyy Institut Razvedochnoy Geofiziki (All Union Institute of Prospecting Geophysics, at Leningrad): A. A. Logachev.

(11) Astronomicheskiy Institut im Shternberga (Sternberg Astronomical Institute, Moscow).

(12) Astronomicheskiy Institut (Astronomical Institute at Leningrad, now Institute of Theoretical Astronomy, U.S.S.R. Ac.Sc.). Formerly very active in field work (V.A. Numerov, A.M. Gizhitskiy, Zhongolovich), now mostly theoretical work.

(13) Poltavskaya Gravimetricheskaya Observatoriya (Poltava Gravimetric Observatory), very active in surveys in the Ukraine and Caucasus (A. Y. Orlov, V.A. Yelistratov, D. V. Pyaskovskiy).

(14) Tashkentskaya Astronomicheskaya Observatoriya (Tashkent Astronomical Observatory): P. A. Savitskiy, very active in Central Asia.

(15) Leningradskiy Universitet (Leningrad University) P. M. Gorshkov, surveys mostly in Central Asia.

(16) Moskovskiy Universitet (Moscow University). This group (Sorokin) made numerous submarine determinations of gravity.

(17) Kazanskiy Universitet (Kazan' University with its two astronomical observatories, (Engelhardt and the University): Y. A. Dyukov, N.A. Chudovichev. Surveys of the Ural regions and Kazakhstan.

(18) Vsesoyuznyy N.I. Arkticheskiy Institut (All Union Research Arctic Institute and other organizations of the Glavsevmorput'): Gravity Surveys in the Arctic. Fedorov, Zhongolovich, Vorob'yev.

All these organizations are publishing a tremendous amount of material in professional journals, reports, books, etc. Only a few of the most important of these publications are mentioned here:

(1) Geodezist, a professional journal devoted to geodesy and allied subjects. Gravimetry occupies a prominent place. The journal started in 1925. Only Vol. 1-16 (1926-1940) are available at DLC QB 296.R813.

(2) Sbornik Nauchno-Tekhnicheskikh i Proizvodstvennykh Statey po Geodezii, Kartografii, Topografii, Aeros"yemke i Gravimetrii. QB 301.R8, Vol. 1-24 (1941-49). Vols. 1-8; 16; 20-24 available. Much useful material here, but no actual data on surveys.

(3) Trudy Ts. N. I. Instituta Geodezii, Aeros"yemki i Kartografii, QB 275.M64, Vols. 1-59 (1931-50). Vols. 1-8; 11-13; 15-18; 20-26; 32-33; 36; 38; 42; 45; 48; 50-51; 59, are available. Some of these volumes are wholly devoted to gravimetry.

(4) Sbornik of same Institute. Vols. 1-10 (1939-41) are available.

(5) Trudy Geofizicheskogo Instituta Ak. N. QE 531.A45 (Before No. 128 Trudy Seysmologicheskogo Instituta). Available 1-105; 118-19; 121; 130-132; 135; 138 (1930-50). Theoretical and reports of gravity expeditions.

(6) Byulleten' Astronomicheskogo Instituta (since No. 53 Byull. Inst. Teoret. Astronomii) Vyp. 1-61 (1923-50). All available. Many data on gravity surveys.

(7) Various publications of universities of Moscow, Leningrad, Kazan', etc. The best source of detailed gravity data. Especially important are the publications of the Poltava Gravimetric Observatory which have not been found to date.

(8) Publications of various expeditions and survey reports on separate regions. Many hundreds of volumes which will have to be examined for gravity data.

The most important centers of training in gravimetry are the following:

Universities of Moscow and Leningrad.

Moscow and Novosibirsk Institutes of Engineers in Geodesy, Photogrammetry and Cartography.

Moscow Geologic Prospecting Institute.

Moscow Oil Institute.

L'vov Polytechnical Institute

Military Engineering Academy.

In view of the centralization of all gravimetric surveys in Russia and free accessibility to foreign data, the Russians must have a much clearer idea of the status of gravimetry the world over than we have. According to Molodenskiy and Fedynskiy they maintain a card catalogue of all pendulum measures which by 1947 contained 25,000 stations. They also mention their gravity map of the world and a gravity map of Europe and of the U.S.S.R. on a scale of 1:1,000,000. This latter must have been a very large undertaking.

Variometric determinations of gravity for mineral deposit surveys run into many hundreds of thousands. The same authors give the status of variometric surveys for oil alone as of 1945 as follows:

1925-1930	11,600	measures
1931-1935	47,700	"
1936-1940	76,000	"
1941-1945	81,900	"
Total	217,200	

There is also much material dealing with the application of gravity data to geodetic problems. As an example we may take a paper by Dubovskoy (Geodezist, 1940, No. 11, pp. 12-30) who considers the area just south of the Aral Sea, 40° - 44° N, 57° - 62° E, where gravity stations are situated 70-100 klm. apart. There are five astropoints in this region. It is calculated that the astronomic-geodetic differences in this area can be represented by formulae:

$$d\xi'' = +6''.03 - 0.705\,(\phi^\circ - 40^\circ) + 0.369\,(\lambda^\circ - 50^\circ)$$

$$d\eta'' = -4''.39 + 0.045\,(\phi^\circ - 40^\circ) - 0.195\,(\lambda^\circ - 50^\circ)$$

A comparison of 22 astro-geodetic points in this region shows the mean errors:

$$\epsilon_\xi = \pm 1''56 \text{ or } 48 \text{ meters}$$

$$\epsilon_\eta = \pm 1''68 \text{ or } 51 \text{ meters}$$

which is considered satisfactory for the control of 1:200,000 maps tied to the main Siberian geodetic network. The author points out that a few more gravity determinations in the vicinity of astropoints would reduce the mean errors to 0''6 - 0''8, quite satisfactory for maps of the scale 1:100,000. It is to be remembered that an error of 1 mlg. in the determination of gravity usually corresponds to an error of only ± 0''1 in ξ or η, or that for this purpose the gravity measures need not be extremely precise.

AVAILABILITY OF GRAVITY MATERIAL

Analysis of Russian material relating to gravity makes it quite evident that most of the original data have never been published. There is frequent reference to a card catalogue maintained by the Moscow Establishment of the Main Directorate of State Survey and Cartography (Moskovskoye Predpriyatiye Glavnogo Upravleniya Geodezii i Kartografii), which appears to be the central office for the collection of gravimetric data. The available material at the present time consists of:

(a) Reports of original pendulum observations published mostly by purely scientific institutions such as the Astronomical Institute (Leningrad), astronomical observatories of Kazan', Tashkent, Moscow, etc. Of such sources over 60 have been located. They cover the situation up to about the year 1935, and therefore are restricted mostly to European Russia, Caucasus, Ural, Central Asia and parts of Southern Siberia. Altogether data on 2594 points have been located in such sources.

(b) Maps of gravity anomalies based on pendulum measures. These are published usually in connection with problems of geology. Over 50 of such maps have been located and some of them are of quite recent origin (1950). They indicate not only the structure of the gravity field in particular areas but some of them give also numerical values of anomalies. These can be easily extracted to supplement our information. There are also a number of maps based on variometer observations and restricted to small areas. While source (a) has been largely exhausted and only a few hundred more gravity points can be expected to be found in a more intensive search, source (b) has been hardly touched.

(c) Theoretical and descriptive papers which often quote more recent information otherwise not available.

In sources (b) and (c) we find sometimes gravity profiles, that is the distribution of gravity approximately along the great circle often to the extent of several hundred kilometers. 21 of such profiles have been found and they sometimes supply more exact information than source (b).

(d) From time to time the Russians publish official catalogues of pendulum gravity data reduced to a common system according to a definite plan. Of these catalogues three are known to be in existence:

(1) Catalogue of [illegible] containing all determinations up to the year 1922: 532 points.

(2) Catalogue of Kazanskiy, Mikhaylov and Numerov containing all determinations up to the year 1933. Published in 1934: 2,488 points.

(3) Catalogue of all determinations up to the year 1938 published in 1944 by the Glavnoye Upravleniye Geodezii i Kartografii: 10,125 points.

Of these catalogues only (1) is available, and (2) covers approximately the same period of time as covered by original observations. Catalogue (3) on the other hand would be a very significant addition to our knowledge of the gravitational field of the U.S.S.R. and all effort should be made to obtain it.

We have further available a catalogue of N. F. Zhuravlev published in 1940 in which gravimetric data for 10,712 points are given distributed throughout the world. Of these 6,253 points fall into the territory of the U.S.S.R. in its pre-war boundaries. The Zhuravlev catalogue is substantially complete up to the year 1936.

This catalogue even though published by the Sternberg Astronomical Institute, one of the most active institutions in gravimetric survey, is not an official catalogue. It is merely an appendix to an article on the shape of the earth determined from gravimetric observations. The data were copied from the card catalogue of the Moscow Establishment.

As usual with catalogues of this size there are numerous misprints and errors some of which are quite evident, but some others are of a kind that can be ascertained only after considerable labor.

The primary sources examined so far give information on 2,244 points entering into the Zhuravlev catalogue. They indicate an abundance of misprints and errors thus advising considerable caution in the use of this catalogue.

We have then at present the following pendulum gravity data in the territory of the U.S.S.R.:

From Zhuravlev's catalogue	6,253	points
Others not in the catalogue	350	points
Total	6,603	points

The distribution of these data is given in Figure 1 with the number of pendulum points for each rectangle 5° latitude x 5° longitude. As has been said before, the Russian gravimetrists consider one pendulum observation per 1,000 square klm. the minimum density necessary to insure the correct tracing of gravity anomalies. In Figure 2 the rectangles have an area approximately 150,000 sq. klm. Thus to satisfy the above criterion we should have about 150 points in each rectangle. A glance at the map shows that only 16 rectangles, and that mostly in European Russia, have the sufficient density of points. Roughly speaking, the territory south and west of the great circle Leningrad-Irkutsk can be considered as fairly well covered. There is of course no doubt that Northern and Eastern Siberia is well covered by gravity measures (as follows from a discussion in 1947 of such things as the great Yakutsk gravity anomaly) but at present at least they are not available to us.

The coverage by the gravity anomaly maps (figure 1) is also restricted to the same area of the U.S.S.R., that is south and west of the great circle Leningrad-Irkutsk as that of pendulum measures, with a few exceptions east of Lake Baykal (areas 39, 40 and 41). For many of the areas, however, the information from the gravity maps is much more up-to-date and complete than from individual measures. Nevertheless at the present time practically nothing is available on the structure of the gravity field in Northern and Eastern Siberia, the Pacific Coast and Kamchatka.

The lists of available maps of gravity anomalies and gravity profiles are given in Appendix I and II which identify the areas and indicate the year when they were published.

THE PROBLEM OF RELIABILITY

With the use of many measures made by different observers with different equipment and often many years ago the problem of reliability of such measures is of the greatest importance. As usual in such cases no general statement can safely be made. Each case must be considered separately. It is known, for instance, that some of the measures made by Zalesskiy in Central Asia about 50 years ago are badly in error, but on the whole this observer has an excellent reputation. Errors are quite often due to wrong value for altitude or improper connection with the primary station.

Some elucidation on this point can be found in an article by Yu. D. Bulanzhe on the secular variation of the force of gravity (Trudy Soveshchaniya po Metodam Izucheniya Dvizheniy i Deformatsiy Zemnoy Kory, 1948, pp. 175-182). Previously M. S. Abakelia had published a paper in which he compared the old and new determinations in the Caucasus and came to the conclusion that there is a definite variation in time in the value of the force of gravity in this region.

Bulanzhe takes 14 points in the Caucasus for which the place of old observations could be reliably identified and shows that with proper reduction of the older data, the new values are in complete agreement with the old ones, although the elapsed time interval was in some cases 32 years. From this and other examples given by the author there is no reason to suspect secular variations of gravity within the precision of observations. This result also indicates the dependability of older measures at least for the regions considered in this paper. Thus for Tbilisi we have:

Determinations 1903 - 1909	g 980177.5 mlg. ± 1.8 mlg. (mean error)
Determinations 1931 - 1936	g 980177.1 mlg. ± 1.0 mlg. (mean error)

THEORY

The development of the theory of gravimetry in its various aspects in the U.S.S.R. has been phenomenal. Apparently there is no restriction on the publication of this material, and our coverage in this respect is nearly complete. In the interval 1930-51 at least 300 papers on theory were published as well as a dozen text-books.

The topics most frequently discussed are:

(a) general theory of the gravitational field of the earth.

(b) applications to the determination of the shape of the earth.

(c) applications to the determination of the deflection of the vertical.

(d) study of systematic errors of pendulum and other observations.

INSTRUMENTATION

The manufacture of torsion-balance variometers was begun in 1925 at the Academy of Sciences. The manufacture of suspension threads for these instruments was not organized until 1938. In 1947 variometers were made at the plant, "Geologorazvedka" (Geological Survey) and pendulum apparatus at the plant, "Aerogeopribor" (Aerial-Geodetic instruments).

There has been considerable activity in the design and manufacture of auxiliary apparatus to increase the precision of pendulum measures. Especially active in this respect was L. V. Sorokin (resonance relay, chronoscope, optical counter, etc.). Further improvements in the design of the Vening-Meinesz apparatus for sea-measurements were made by S.E. Aleksandrov at the Leningrad Astronomical Institute.

First gravimeters of the Lejay type were constructed at the TsNIIGAiK under the direction of G. I. Rudakovskiy. They were very successfully used in carrying out the general gravity survey.

At the same institute a new type of a spring gravimeter was developed by M. S. Molodenskiy. Even the first instruments of this type gave a precision of determination of 1-2 mlg.

In 1943 further progress in the construction of the Molodenskiy gravimeter was made at the NIIPG (Institute of Applied Geophysics). In 1947 several dozen of these instruments were in operation in various parts of the U.S.S.R.

New developments in instrumentation seem to lead to the improvement of gravimeters of the Lejay and spring type and, in general, a drift from free-pendulum instruments is indicated. This work is carried on at the IRG (Institute of Prospecting Geophysics) and the Geophysical Institute of the Academy of Sciences.

Russian gravimetrists express the opinion that the greatest obstacle in the gravimetric survey is not so much in the limitations of the gravimetric instruments as in the absence of a simple and reliable instrument for the determination of altitude of field gravimetric stations. Work to solve this problem is going on in a number of research institutes.

ASTRONOMIC POSITIONS

Astronomic determinations of latitude gives the direction of the local vertical which is not necessarily normal to the adopted surface of the reference ellipsoid. The angle between the normal to the ellipsoid and the direction of the astronomical zenith is the deflection of the vertical.

The determination of longitude involves the knowledge of the local time and some standard time. In general, determinations of longitude are differential, that is the longitude of a place from Greenwich is found as a sum of several differences of longitude.

Astronomic positions can be used for a variety of purposes requiring different degrees of precision. It is usually necessary to take into account the following factors:

(1) Deflection of the astronomical vertical produced by the distribution of masses above and below the surface of the geoid. This is by far the most important reason why astronomic determinations seldom can be used for cartographic controls as given by the observer. We define the differences

$$\xi = (\phi_a - \phi_g) \; ; \; \eta = (\lambda_a - \lambda_g)\cos\phi$$

where $\underline{a}$ stands for astronomical, and $\underline{g}$ for geodetic coordinates. For most plain regions in the U.S.S.R. the quantities ξ and η are in the neighborhood of 3", but there are several regions for which they reach amounts 20 times the above. These are also the regions of gravity anomalies, (and often also of magnetic anomalies) the best known of which is centered around Moscow.

The Moscow anomaly has been studied in great detail, and we have for it about 200 astronomic determinations of latitude and about 150 gravity determinations. In this region, as is usually the case, the deflection of the vertical changes very rapidly, yet in a very definite pattern. At the University Observatory in Moscow ξ is equal to +10"5, but 20 klm. north of it is -3"0, the total variation being 13"5.

Similar anomalies exist in the region of Kursk and Chernigov. In Asia we have the well studied Fergana Valley anomaly and probably the most remarkable of all, the Lake Baykal anomaly. Nothing definite is known about the latter one, except that it is very large, and the deflection of the vertical may be as great as 50".

(2) Variation in the position of the rotational pole of the earth. This may attain an amplitude of 0"6 and consists of both periodic (that is predictable) and secular terms. There is much material on this subject published by the Russian writers and it is now being studied in detail.

(3) Variation in longitude not depending on the variation of the pole. In 1926 and 1933 the International Astronomical Union and the International Association of Geodesy organized a working plan to make new determinations of longitude at selected observatories throughout the world. The results are hardly encouraging since most observatories showed much larger variations in longitude than could be explained by accidental errors. The longitude of Pulkovo, for instance, has changed by $0^{s}.009$, that is in angular measure 0"135, and this is a small variation. For Potsdam this variation is $0^{s}.016$ and for Melbourne, $0^{s}.148$. The variation is not consistent with the theory of continental drift (Wegener's hypotheses) and is not generally considered as real. It probably has something to do with the transmission of radio signals. In fact, the French astronomer, Stoyko, found distinct periodicity in the difference of longitude between various places with a period of 11 years and amplitude $0^{s}.06$, that is, 0"9. This suggests the influence of the sun-spot cycle on the ionosphere but at the present time the whole problem is still debated.

In any precise treatment of astronomic longitudes a knowledge of the Russian time service is necessary. Fortunately there is an abundance of material on this subject and necessary studies are being made.

(4) Systematic differences in catalogues of star positions used for geodetic purposes. These may affect the determinations of place positions by 0"1 and possibly more.

(5) Finally, in the combination of geodetic and astronomic positions the warping of the selected ellipsoid of reference in respect to the geoid must be considered. This may introduce serious errors. The Russians have found that the Bessel spheroid used before 1942 gives for the center of Siberia discrepancies of over 900 meters, or something like 30" in latitude. This was one of the reasons that the recomputation of a reference ellipsoid became necessary. Now they claim (M.S. Zverev, Astr. Zh. S. U. Vol. 28, 1951, pp. 123-138) that recomputation of the elements of the ellipsoid based on up-to-date material on the triangulation of the U.S.A. gives values of the major semi-axis (a) and flattening (ε) much nearer to the Krasovskiy ellipsoid than that of Hayford.

The elements of the most commonly used spheroids are as follows:

	a	ε	
Bessel 1841	6377397 met	1:299.2	U.S.S.R. before 1942
Clarke 1866	6378206	1:295.0	U.S.A.
Clarke 1880	6378249	1:293.5	
Hayford 1909	6378388 ± 18	1:297.0 ± 0.5	International
Krasovskiy	6378245 ± 10	1:298.3 ± 0.3	U.S.S.R. after 1942

The introduction of a new ellipsoid of reference differing so much from the ellipsoid previously adopted has introduced much confusion in Russian cartography. This confusion is bound to exist for some years yet until all maps based on Bessel's spheroid have been re-issued.

Despite the Russian claims for the final solution of the problem of the spheroid they admit themselves (Bulanzhe, Izv. Ak. N., Ser. Geogr. i Geof., Vol. 11, 1947, pp. 509-510) that more recent measures of gravity in the Arctic show the geoid to be 50 to 80 meters below the surface of Krasovskiy's ellipsoid.

In regard to the use of astronomical determinations for cartographic purposes we must distinguish between two kinds of errors: (a) chance or internal errors resulting in scattering of observed values and (b) systematic or external errors distorting the obtained result. The systematic errors are very difficult to evaluate as they require a simultaneous adjustment of a long series of observations for which the necessary details are sometimes lacking. They are much more important in the determination of longitude than in the determination of latitude.

For the evaluation of internal errors we have simple mathematical criteria based on the amount of departure of the arithmetic mean from individual results. Such are mean errors and probable errors. Probable error has a definite physical meaning: it is the 50 percent probability that the true value is within the limits indicated by the probable error.

The relation between these two kinds of error is very simple: probable error = 0.675 mean error.

The Russians sometimes divide their astronomical points into 9 classes according to the size of mean errors, but this classification has little significance and is not generally adopted.

For cartographic purposes astropoints should posses (a) a certain accuracy depending on the scale of the map and (b) be referred to a recognizable geographic object such as a church, shore of a lake, etc.

The required accuracy of control depends not only on the scale but also on arbitrary assumptions. As defined in the U. S. Coast and Geodetic Survey Topographic Manual, 1949, p. 2:

"For maps published at scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error more than 1/30 inch, measured at publication scale; for maps published at scales of 1:20,000 or smaller, this tolerance is 1/50 inch."

Translated into the latitudinal scale of magnitudes (which for longitudes should be multiplied by a secant of latitude) we have the following requirements:

Scale	Tolerance	Corresponding Probable Error
1:1,000,000	17"6	7"2
1:200,000	3"5	1"44
1:100,000	1"8	0"72
1:20,000	0"4	0"14

Whereas a competent observer using only a sextant can determine latitude within a minute of arc, the determination of longitude has always been much more difficult. Before 1920 practically all longitude determinations were based on transportation of chronometers. Observations in the Arctic regions are further complicated by low temperatures in the winter and lack of dark sky in the summer. Yet here again much depends on the observer. Some of the observers even a hundred years ago obtained good material using such cumbersome methods as occultation of stars by the moon for the determination of longitude.

The observations by the famous Arctic explorer, F. Vrangel', made in 1820-1824 were checked in 1928 by Agafonov who used radio for the determination of longitudes with the following results:

Nizhne-Kolymsk	Vrangel' 1824	68°31'48" N;	160°56'35" E.
	Agafonov	68°31'54".4 N;	160°55'30".3 E.
	Difference	- 6".4	+ 1'04".7

Thus even in 1824 some points in Eastern Siberia were determined within half a mile precision.

However, no general statement can be made in this respect. Some observations are good, while others are obviously wrong. In order to make the best cartographic use of astronomical determinations in the U.S.S.R. a systematic study of the material already obtained is necessary. This includes in the first place the older longitude determinations (1870-1920) by means of telegraph and more recently by radio. Of such, over 1,200 are already known with the probable error 1" or better (represented in figure 3). In some cases even the deflections of the vertical are known, in others they can be computed. Such determinations can be used for the control of maps on a scale of 1:100,000 or even larger.

It is to be distinctly understood that the material already found (about 8,000 astropoints represented in figure 4) is the raw material which is, on the whole, good enough for the control of the charts and maps on the scale of 1:1,000,000 or smaller. For the control of maps of larger scale a careful discussion of all longitudes in the U.S.S.R. determined with necessary precision is called for. Even the task of selection of points which would satisfy such requirements is not an easy matter.

An attempt to adjust astronomical longitudes in the U.S.S.R. was made by A. Berroth in 1921 in his article "Ausgleichung des russischen Längennetzes nebst Gewichtsbestimmung", (Astronomische Nachrichten, Vol. 215, 1922, pp. 19-27). His adjustment is based only on 28 points the easternmost of which is Orsk, longitude 58°33' E. Not even Tashkent is included in this scheme. Furthermore, for practically every one of Berroth's points we have more recent determinations of longitude, and can extend adjustment to Vladivostok and connect the latter with Tokyo.

Without such careful adjustment the small probable errors of longitude determinations are deceptive.

To illustrate the point, let us take a specific example. The coordinates of the city of Blagoveshchensk on the Amur (cross on the belfry of the Polkovo-Nikol'skaya church) were determined telegraphically by:

Sharnhorst 1873	50°15'43".97 N	127°30'50".00 E
Akhmamet'yev 1911	50°15'43".73	127°30'49".54
Mean	50°15'43".85	127°30'49".77
Probable error	± 0".08	± 0".15

Can we conclude from this that the coordinates of this point in respect to Greenwich are known with a probable error of only 8 feet? We certainly cannot. We have to see how this point was connected with Pulkovo and what longitude of Pulkovo was adopted in the final derivation of the longitude of Blagoveshchensk.

On the basis of Berroth's adjustment of longitudes the fundamental point of Sharnhorst in Sverdlovsk is in error by - 0"675, so that all points in Siberia determined by Sharnhorst should be moved westward by that amount. This procedure would then result in longitudes of Blagoveshchensk by:

Sharnhorst 1873	127°30'49"33
Akhmamet'yev 1911	49"54
Mean	127°30'49"44 ± 0"08

Thus, in spite of the original probable error of 0"15 the discrepancy between the two means is 0"33. This, of course, is only half of the story. We must consider the relative weights of the determinations of 1873 and 1911, use modern values of the difference in longitude between intermediate points and develop a more comprehensive treatment of the subject than was given to it by Berroth. Once the position of this main point in Blagoveshchensk is settled, the position of half-a-dozen other points in this city become known with the same precision as the differential measures of these points in reference to the church are known. The same situation obtains in practically every Russian city. In this connection the value of old Russian maps should be emphasized. A map of the city of Blagoveshchensk of, say 1870, may seem to be of very little use in 1951. However, the original astropoints, as well as various features of the city based on such astropoints can be identified only by using such old maps, which then can be compared with more recent material.

SOURCES OF ASTRONOMIC POSITIONS

Astronomic and geodetic positions in the U.S.S.R. are sometimes given in catalogues arranged either according to the International Map of the World System or according to geographic regions.

The following general remarks can be made about all these catalogues.

(1) They are of very unequal value. In some of them observed coordinates are those given by the observer, in some others an attempt was made to work out a rational system of longitudes. Even then such an attempt was made the results cannot be accepted without further inquiry.

Thus we have a determination for Kushkinskiy:

$$35°17'03''.0 \pm 0''.27 \text{ N}, \ 62°20'50''.0 \pm 0''.61 \text{ E}.$$

On the basis of probable errors it would seem to be a very precise observation. However, the probable errors refer only to the difference in longitude between Kushkinskiy and Tashkent. The longitude of Tashkent in this example depends on the longitude of Omsk, etc. We have here the following chain of differences in longitude:

Kushkinskiy-Tashkent-Omsk-Sverdlovsk-Pulkovo-Greenwich with each step subject to an error.

When we deal with longitudes determined by transportation of chronometers the chain may include ten and more links.

(2) The catalogues seldom include an adequate description of the astropoint to make it usable for cartographic work. It is necessary to go to the original publication for a detailed description and for a sketch.

(3) The catalogues often contain errors and misprints.

An effort has been made [illegible] in which these catalogues are based. This is, of course, a time-consuming work but it is absolutely necessary if we want to obtain reliable information.

The catalogues and original observations run into hundreds of references. Only the most important catalogues will be mentioned here:

(1) Katalog Osnovnykh Punktov SSSR. Chast' 1: Astronomicheskiye Punkty.

These catalogues arranged in the International Map of the World System were being published in the period 1927-1930 by the Vyssheye Geodezicheskiye Upravleniye (Supreme Geodetic Office). They consist of three parts:

I Astronomical Points

II Triangulation Points

III Leveling Data

Detailed references only to Part I have been found in Russian literature. It is not known whether part II and III were ever published. Of Part I, 64 catalogues were published up to 1939 (M. D. Bonch-Bruyevich, Geodeziya, Vol. 6, p. 122). No further information on these catalogues is available and perhaps the whole edition (planned to consist of 214 volumes) has been discontinued.

These catalogues have a definite system of longitudes based on Berroth's adjustment. At best they represent the older material, up to about 1925, and are incomplete. The descriptions of astropoints is good but for sketches reference to original material is still necessary.

The following 21 catalogues have been found:

O-42, 42, 43, 44, 45, 46, 47, 48

N-42, 43, 44, 45, 46

M-40, 43, 44, 45

J-41, 42, 43

I-41

The following 39 catalogues are referred to in Russian geodetic literature; but have not been found by us:

Q-39, 40, 41, 42, 43, 44, 45, 46, 47, 48

P-36, 37, 38, 39, 40, 41, 43

O-39, 31, 39, 50

N-40, 41, 47

M-41, 42

L-40, 41, 42, 43, 44, 45

K-40, 41, 42, 43, 44

I-42, 43

This leaves unaccounted for four other catalogues that are known to have been published.

Each of these catalogues contains about 100 astropoints.

(2) Regional catalogues. Of these the most important are:

(a) Sergeyevskiy, Kara Sea Region, material up to 1935....841 astropoints

(b) Bukh, Far East Region material, up to 1928............603 "

(c) Glazenap, The Pechora River Basin, up to 1925.........470 "

(d) Glazenap, Yakutia, up to 1929........................750 "

(e) Belyayev and Kopylov, Kazakhstan, up to 1928.........1532 "

(f) Vasil'yev, Chukotsk Peninsula, up to 1934............ 100 "

(g) Zalesskiy, Turkestan (partly overlapping e), up to 1911 956 "

(h) Anert, Transbaykalia, up to 1913....................453 "

Total 5705

(3) Original sources such as reports of expeditions, journals etc. Of such sources, about 160 have been found so far. They yield about 1600 astropoints.

We have then the total number of astronomic positions in the U.S.S.R.:

(1)	Systematic Catalogues	2,000
(2)	Regional Catalogues	5,700
(3)	Original Sources	1,600
	Total	9,300

Considering that there is some overlapping in these three sources we may put the final figure at 8,000 astropoints.

We must note that here again as was noted previously in respect to gravity determinations, our information stops at about 1935. Apparently at about this time the Russian Government realized the strategic importance of such information and took measures to prevent its leakage abroad.

It is known, however, that results of astronomic determinations (as contrasted with gravity determinations) continued to be published. Up to the year 1923 the bulk of astronomic determinations was made by the Korpus Voyennykh Topografov (Corps of Military Topographers). Comparatively few were made by other agencies such as the Hydrographic Office, Pereselencheskoye Upravleniye (Resettlement Office), scientific expeditions, etc.

After 1923 we have four volumes on astronomic observations covering the years 1924, 1925, 1926 and 1927 published by the Geodezicheskiy Komitet and its successor, Glavnoye Geodezicheskoye Upravleniye. All this material is available, and our knowledge up to 1928 is probably complete.

After 1932 two agencies were prominent in this work:

(1) The Arctic Institute and The Hydrographic Office of the Glavsevmorput' covering the territory north of the 60° parallel. Numerous reports on their activity have been

f[illegible] publications [illegible] astronomic observations are not available although known to have been published.

(2) Glavnoye Upravleniye Geodezii i Kartografii is publishing reports of astronomic as well as other observations. None of this material has been found.

The reports on astronomic observations are evidently a continuation of the similar reports by the Glavnoye Geodezicheskoye Upravleniye (1924-27). They give material for each year (published two or three years later) and constitute Series A (astronomic). Volume A-1 contains the material for the year 1928, and Volume A-XIII for the year 1940. A-XIV for the years 1941-42 was published in 1948, and is the latest to which a reference has been found. The Russian title of these reports is "Otchet po Astronomicheskim Opredeleniyam".

There are three other series published by the same agency:

Otchet po Triangulyatsii I-Klassa (Triangulation I-order), last known volume T-XXVI.

Otchet po Nevilirnym Rubotam I i II Klassov (Leveling of I and II order), last known volume H-X

Otchet po Izucheniyu Bazisov (Base Lines), last known volume Б - XIV.

CONCLUSION

In order to utilize the geodetic gravimetry method for the improvement of our knowledge of cartography of the U.S.S.R., as well as for other problems of importance from the point of view of national defense, we must deal with the following situation:

(a) Our knowledge of numerical data both in gravity and astronomic positions in the U.S.S.R. is on the level of 1935-36. Only the acquisition of certain printed (as described in the text) but now not available materials will bring our knowledge in these matters to the present level of science in the U.S.S.R.

(b) Our knowledge of progress of such work, theoretical investigation, and instrumentation in the U.S.S.R. is probably nearly complete and up-to-date.

(c) In regard to numerical data we have at our disposal about 6,600 determinations of gravity, and about 8,000 determinations of astronomic positions. The gravity data are supplemented by 56 gravity anomaly maps some of which are of quite recent origin.

(d) The gravity data and most astronomical points cover the region South and West of the great circle Leningrad-Irkutsk. For this region an application of the Kazanskiy-Molodenskiy method, or similar methods developed by Heiskanan and others will undoubtedly improve our knowledge of the deviation of the vertical. In particular, a preparation of gravity anomaly map with a contour interval 10 mlg. is quite feasible. This map should allow the determination of the deflection of the vertical with the precision 1", or better. North and East of this great circle we have astronomical determinations mostly along the course of rivers, but practically no gravity data.

(e) The available astronomical data are the raw material which can be used as given only for the control of maps of a scale 1:1,000,000 and smaller. A careful study and reduction of this material into a homogenous system is necessary to make it usable for any precise control.

(f) The knowledge of Russian geodesists in regard to foreign work is very detailed and up-to-date.

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LIST OF AREAS WITH GRAVITY ANOMALY MAPS

PUBLISHED IN RUSSIAN SOURCES

1. Caucasus 41° - 44° N; 40° - 40° E. Contour interval 50 mlg. Yevseyev 1948.
2. Western Ukraine 48° - 51°30' N; 22° - 26° E. Contour interval 25 mlg. Bogdanov 1950.
3. Ukraine 44°30' - 52° N; 26° - 41° E.
   (a) Contour interval 25 mlg. Orlov 1931.
   (b) Contour interval 10 mlg. Galushko 1938.
   (c) Contour interval 10 mlg. Nechiporenko 1935.
4. Carelia and Leningrad Oblast 54° - 66° N; 30° - 40° E. Contour interval 10 mlg. Andreyev 1938.
5. Ural 54° - 57° N; 48° - 54° E. Contour interval 10 mlg. Baranov 1934.
6. Moscow region 54°15' - 57°10' N; 35°40' - 39°20' E. Contour interval 10 mlg. and 1". Kazanskiy 1936; Bulanzhe 1938.
7. Baku region 38° - 42° N; 47° - 50° E. Contour interval 25 mlg. Bonch-Bruyevich 1949.
8. Turkestan region 41°30' - 44° N; 67°30' - 70°10' E. Contour interval 10 mlg. Yeremeyev 1945.
9. Ishimbayevo region 53°15' - 53°30' N; 56° - 56°30' E. Offman 1946.
10. Ural region 53° - 56° N; 56° - 62° E. Contour interval 10 mlg. Yevseyev 1937.
11. Middle Volga 50° - 52° N; 44° - 48° E. Contour interval 10 mlg. Yevseyev 1937.
12. Kazakhstan 40° - 44° N; 57° - 62°15' E. Contour interval 1". Dubovskoy 1940.

13. Central Asia 37° - 44° N; 66° - 76° E. Contour interval 25 mlg. Erola 1941.

14. Dossor region 47°15' - 47°40' N; 52°30' - 53°15' E. Numerov 1931.

15. Lake Baskunchuk 48°05' - 48°20' N; 46°15' - 47° E. Contour interval 2 mlg. Numerov 1931.

16. Groznyy region 43° - 45° N; 44° - 47° E. Numerov 1931.

17. Ural 52° - 57°30' N; 58° - 70° E. Contour interval 10 mlg. Gizhitskiy 1931.

18. Solikamsk region 59°38' N; 56°45' E. Numerov 1931.

19. Ust'Port region 69°30' - 69°42' N; 84°15' - 85° E. Contour interval 1 mlg. Fotiadi 1937.

20. Yurung-Tumus 73°57' - 74°04' N; 111° - 111°40' E. Contour interval 1 mlg. Fotiadi 1935.

21. Kozhevnikova Bay 73°35' - 73°45' N; 110°30' - 111° E. Contour interval 1 mlg. Fotiadi 1937.

22. Lower Volga 47°45' - 48°15' N; 45°50' - 46°25' E. Contour interval 1 mlg. Stepanov 1934.

23. Volga 47°50' - 49°20' N; 46°30' - 48° E. Contour interval 10 mlg. Bogdanov 1934.

24. Lake Elton 49°05' - 49°20' N; 46°40' - 47°10' E. Contour interval 5 mlg. Bogdanov 1934.

25. Ural 47° - 53° N; 56° - 64°30' E. Contour interval 25 mlg. Arkhangel'skiy 1932.

26. Central Asia 43° N - border; 64° - 75° E. Contour interval 25 mlg. Mudretsova 1948.

27. Dnepr-Donets area 48°30' - 52°30' N; 30° - 37° E. Contour interval 10 mlg. Galushko 1938.

28. Dnepr-Donets area 49°20' - 52°40' N; 29° - 37° E. Contour interval 10 mlg. Zavistovskiy 1938.

29. N. W. of Azov Sea, from Melitopol' to Dyurmen'. Contour interval 1 mlg. Zavistovskiy 1938.

30. European Russia. Contour interval 50 mlg. Arkhangel'skiy 1936.

31. Middle Volga, Saratov-Kuybushev. Contour interval 10 mlg. Lukavchenko 1947.

32. Kuban'-Black Sea 44° - 48° N; 34°30' - 40°30' E. Contour interval 10 mlg. Lukavchenko 1947.

33. Azerbaydzhan. Contour interval 10 mlg. Lukavchenko 1947.

34. Irtysh River. 51° - 49° N; 80°30' - 85° E. Gorshkov 1936.

35. Makat Region 47°40' N; 53°16' E. Contour interval 2 mlg. Gubkin 1936.

36. Blyauli Region 47°14' N; 52°55' E. Contour interval 2 mlg. Gubkin 1936.

37. Caucasus 38° - 46° N; 36° E.-Caspian Sea. Contour interval 20 mlg. Abakelia 1936.

38. European Russia, Central Asia, Central Siberia. Contour interval 25 mlg. Arkhangel'skiy 1937.

39. Irkutsk area 51° - 53° N; 103° - 108° E. Contour interval 25 mlg. Arkhangel'skiy 1937.

40. Chita area 52° N.-China boundary; 111° - 116° E. Contour interval 25 mlg. Arkhangel'skiy 1937.

41. Blagoveshchensk area 52° N. - China Boundary; Amur - 138° E. Contour interval 25 mlg. Arkhangel'skiy 1937.

42. Pamir Region 45° N. - boundary; 65° E. - boundary. Contour interval 25 mlg. Arkhangel'skiy 1936.

43. Central Asia. Contour interval 25 mlg. Arkhangel'skiy 1935.

44. European Russia. Contour interval 25 mlg. Arkhangel'skiy 1939.

45. Azerbaydzhan. Contour interval 25 mlg. Arkhangel'skiy 1932.

46. N. W. Caucasus 43° - 44° N; 40°30' - 41°30' E. Contour interval 50 mlg. Gorshkov 1947.

47. European Russia. Contour interval 25 mlg. Arkhangel'skiy 1932.

48. Ukraine and Caucasus. Contour interval 25 mlg. Arkhangel'skiy 1932.

49. Kursk Region 50°51' - 51°52' N; 36°30' - 37°34' E. Aksenov 1928.

50. Mouth of the Yenisey. Contour interval 25 mlg. Arkhangel'skiy 1937.

51. Temir Region 48°45' - 49°30' N; 55° - 57° E. Contour interval 2 mlg. Bazyuk 1931.

52. Romny Region 50°36' - 50°56' N; 31°05' - 31°20' E. Contour interval 1 mlg. Subbotin 1935.

53. Ukraine 46° - 52° N; 37° - 44° E. Contour interval 10 mlg. Andreyev 1941.

54. North of Caspian Sea - 45° - 54° N; 43° - 60° E. Contour interval 10 mlg. Andreyev 1941.

55. Emba Region - 46°15' - 48° N; 52°30' - 53°45' E. Contour interval 4 mlg. Andreyev, 1941.

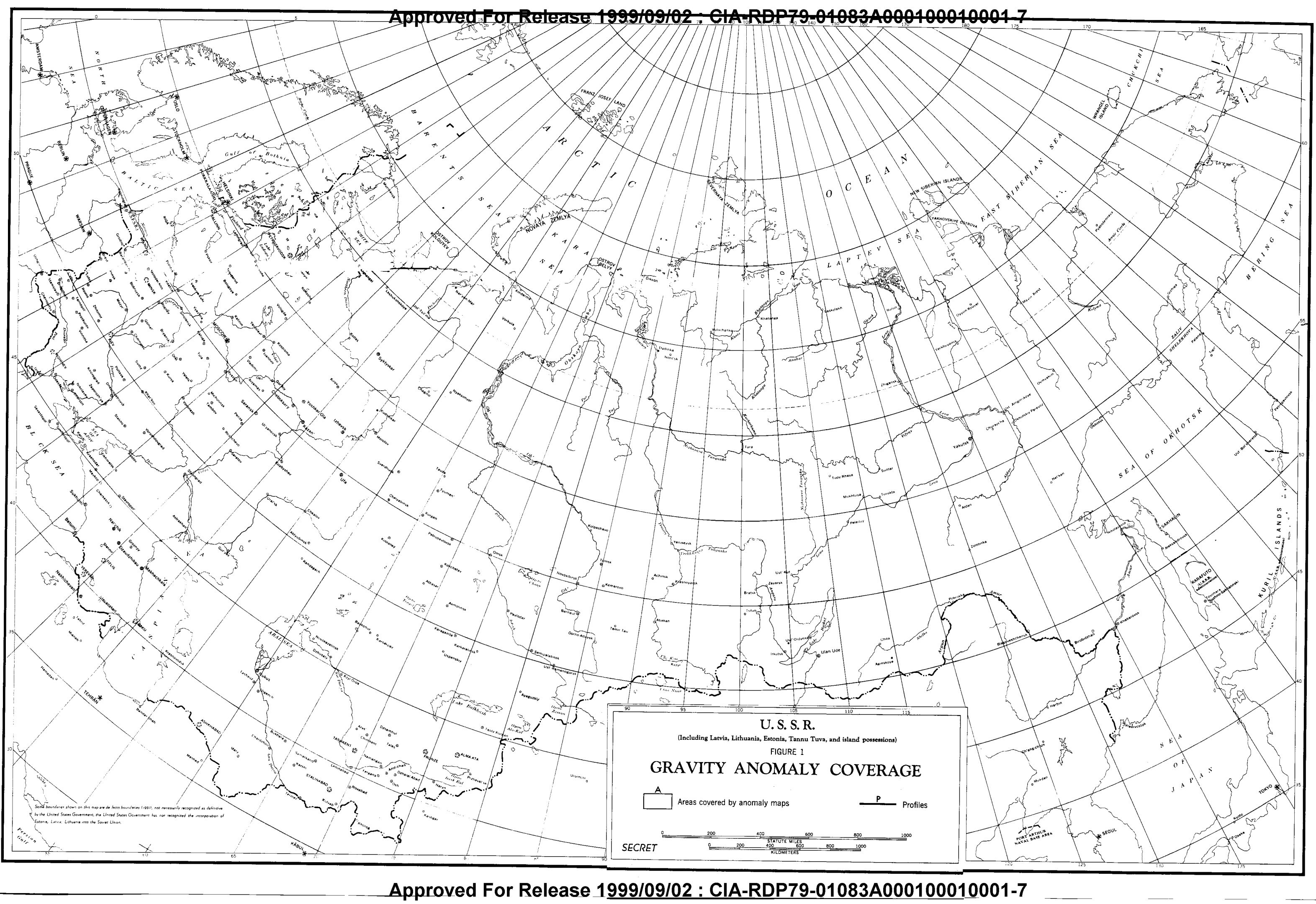
56. Central Bashkiria - 53°10' - 53°30' N; 55°45' - 56°15' E. Contour interval 2 mlg. Andreyev, 1941.

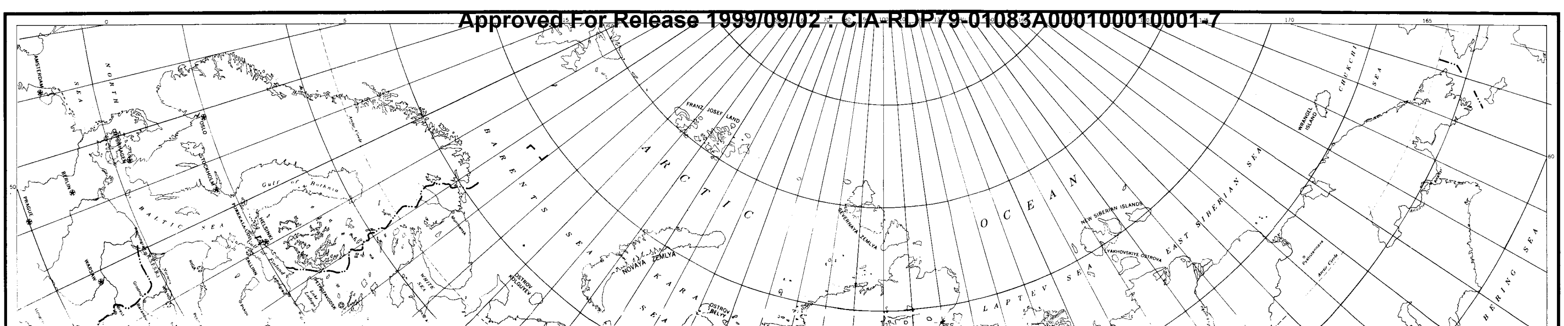
APPENDIX II

LIST OF GRAVITY PROFILES

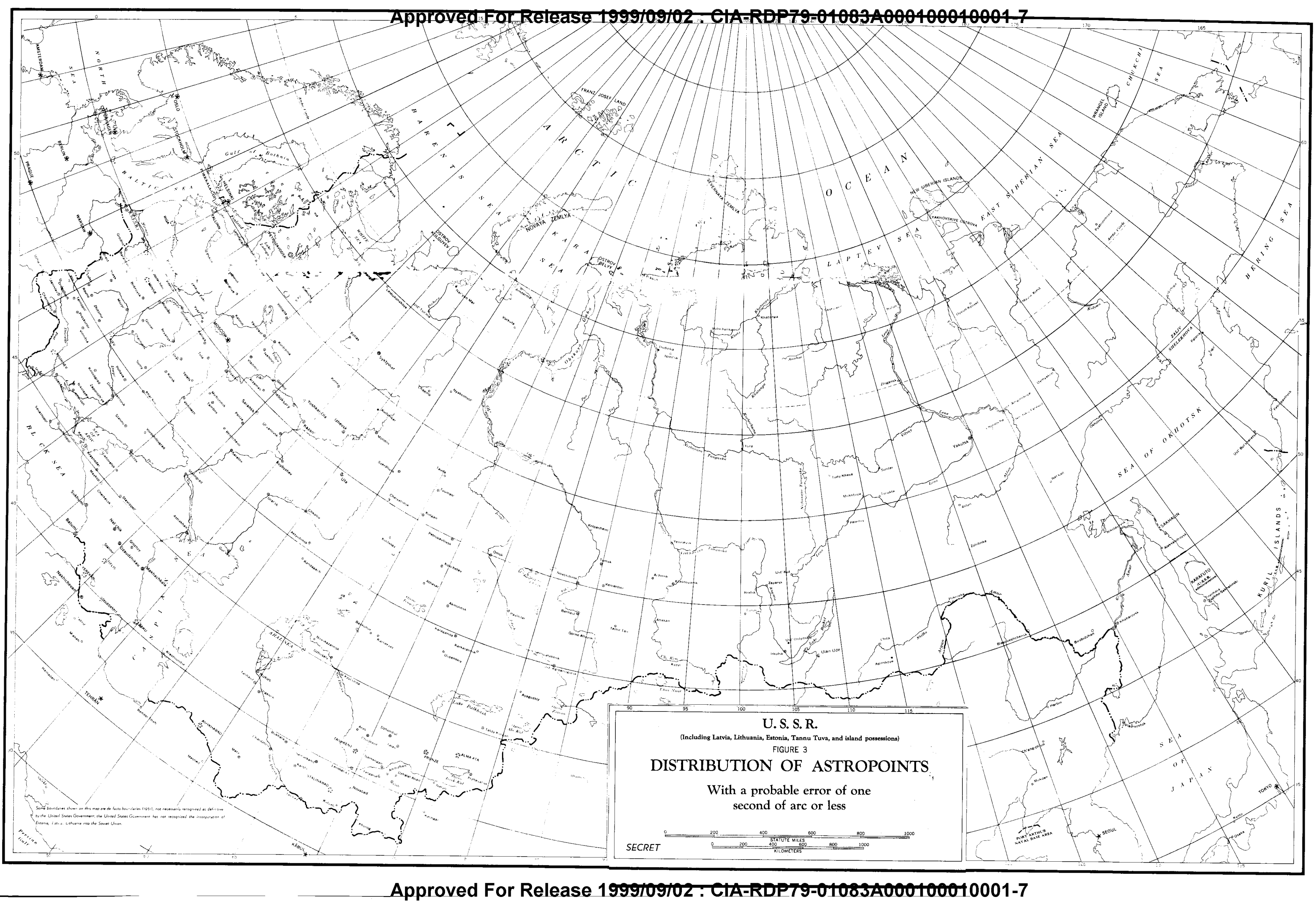
PUBLISHED IN RUSSIAN SOURCES

1.	L'vov-Uzhgorod	Bogdanov	1950
2.	L'vov-Mukachevo	Bogdanov	1950
3.	Khust-Rakov-Galich	Bogdanov	1950
4.	Karaganda-Semipalatinsk	Gorshkov	1936
5.	Sviyazhsk-Sverdlovsk	Dyukov	1931
6.	Ufa-Petropavlovsk	Dyukov	1931
7.	Sokolki-Kotel'nich	Dyukov	1931
8.	Krasnovidovo-Yelabuga	Dyukov	1931
9.	Moscow Meridional section	Pariyskiy Kazanskiy	1932
10.	Sverdlovsk-Omsk	Gorshkov	1931
11.	Zlatoust-Omsk	Gizhitskiy	1931
12.	Kotel'nich-Molotov	Gizhitskiy	1931
13.	Kirov-Kotlas	Gizhitskiy	1931
14.	Priluki-Romny	Galushko	1938
15.	Ovruch-Mogilev	Zavistovskiy	1938
16.	Vyborg-Kursk	Andreyev	1938
17.	Aland Isl.-Perch Navolok	Andreyev	1938
18.	Pori-Veroruksa	Andreyev	1938
19.	Bogorak-Sarykamysh	Mudretsova	1948
20.	Kurgovad-Andizhan	Mudretsova	1948
21.	Surkhan-Chaadag	Mudretsova	1948
22.	Allagrevato-Smokayevo	Andreyev	1941
23.	Manych-Baklanovka	Andreyev	1941
24.	Kamenolomya-Persianovka	Andreyev	1941
25.	Rostov Lishi	Andreyev	1941
26.	Kamyshbosh-Gava	Andreyev	1941


U. S. S. R.
(Including Latvia, Lithuania, Estonia, Tannu Tuva, and island possessions)
FIGURE 1
GRAVITY ANOMALY COVERAGE
A
Areas covered by anomaly maps
P
Profiles
0 200 400 600 800 1000
STATUTE MILES
0 200 400 600 800 1000
KILOMETERS
SECRET
ARCTIC OCEAN
BARENTS SEA
KARA SEA
LAPTEV SEA
EAST SIBERIAN SEA
BERING SEA
SEA OF OKHOTSK
SEA OF JAPAN
BLACK SEA
BALTIC SEA
NORTH SEA
FRANZ JOSEF LAND
NOVAYA ZEMLYA
NEW SIBERIAN ISLANDS
KURIL ISLANDS
Gulf of Bothnia
Ulan Ude
Irkutsk
Chita
Abakan
Kyzyl
Lake Baikal



Approved For Release 1999/09/02 : CIA-RDP79-01083A000100010001-7



U. S. S. R.

(Including Latvia, Lithuania, Estonia, Tannu Tuva, and island possessions)

FIGURE 3

DISTRIBUTION OF ASTROPOINTS

With a probable error of one second of arc or less

SECRET

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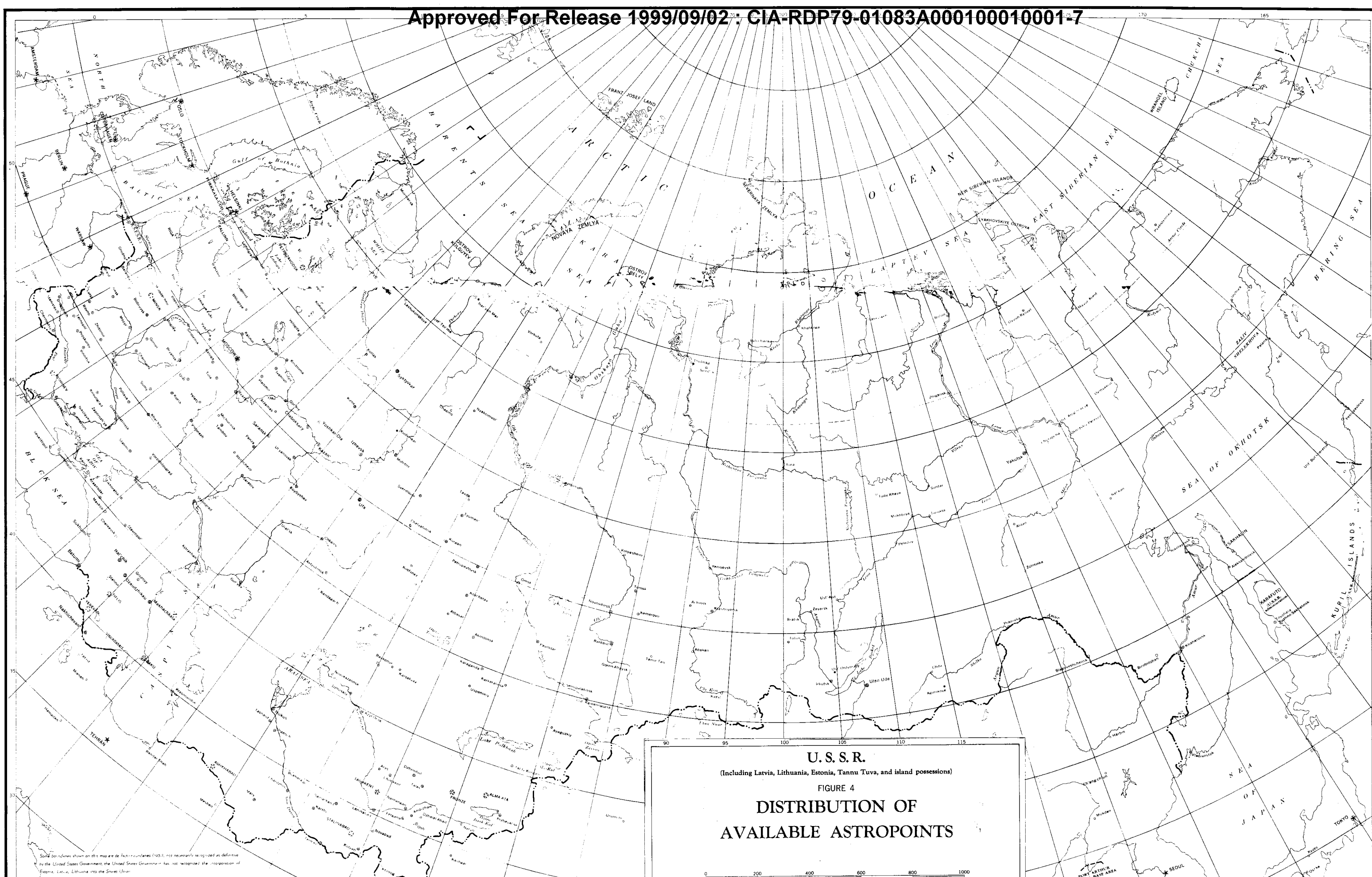

U. S. S. R.

(Including Latvia, Lithuania, Estonia, Tannu Tuva, and island possessions)

FIGURE 4

DISTRIBUTION OF AVAILABLE ASTROPOINTS

CONFIDENTIAL

~~SECRET~~