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USSR Report

SPACE

(FOUO 9/80)

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25 September 1980

USSR REPORT

SPACE

(FOUO 9/80)

CONTENTS

SPACE SCIENCES

UDC 537.591.5

SCINTILLATION STUDIES OF COSMIC RAY VARIATIONS

Moscow STSINTILLYATSIONNYY METOD ISSLEDOVANIY VARIATSIY KOSMICHESKIKH LUCHEY in Russian 1979 signed to press 13 Jul 79 pp 4, 107

[Annotation and Table of Contents from the book by L.I. Dorman, I.Ya. Libin and Ya.L. Blokh, Nauka Publishers, 1,000 copies, 107 pages]

[Text] The basic questions of studying the variations in the intensity of cosmic rays using scintillation instruments are treated in the monograph.

A number of chapters are devoted to the development of new equipment using large plastic scintillometers and the procedure for investigating the variations using this equipment. Original methods of improving the precision and monitoring the stability of the continuous operation of the instruments and the recording of the ionizing components are described. The results of studies of fluctuations and anisotropy as well as their possible relationship to processes in interplanetary space and the galaxy are given. Questions of the utilization of scintillation supertelescopes as cosmic ray spectrographs are treated, as well as the prospects for the development of the scintillation method for studying the variations in cosmic radiation intensity.

The work was carried out within the framework of the scientific cooperation of the academies of sciences of socialist nations on planetary geophysics and is intended for specialists in cosmic rays.

Figures 49; tables 13; 257 bibliographic citations.

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[363-8225]

8225
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LIFE SCIENCES

UDC 629.78:612.111/112.014.2

HEMATOLOGICAL ASPECTS OF SPACEFLIGHT, REPORT I: CYTOLOGICAL CHARACTERISTICS OF PERIPHERAL BLOOD

Moscow PROBLEMY GEMATOLOGII I PERELIVANIYA KROVI in Russian No 5, 1980 manuscript received 4 Oct 79 pp 28-36

/Article by Professor O.K. Gavrilov, corresponding member, USSR Academy of Medical Sciences, Professor G.I. Kozinets, I.A. Bykova, Z.G. Shishkanova, V.P. Matviyenko, I.V. Ryapolova, S.M. Dul'tsina, L.V. Borzova, R.A. Kul'man, O.A. Dyagileva, N.N. Talelenova, V.Ya. Kovner and V.M. Kotel'nikov/

/Text/ The successful completion of extended expeditions into space, during the realization of which man lives and works in space for many months, has already made it possible to regard outer space as a new environment for human habitation. In this field medical science is faced with multifaceted and complex questions concerning the complete adaptation of man in space to unusual conditions for his existence while retaining a high level of ability to do work and preserving the normal course of all vital processes. No less important is the question of man's subsequent complete readaptation upon his return to Earth.

As the result of research done during flights in the "Soyuz" ships and "Salyut" orbital stations, we have obtained reliable evidence that man can adapt successfully to an extended stay in space and do active work under these conditions /6/. Under the influence of factors encountered during spaceflight, there is a rearrangement of the activities of a number of systems and organs that reflects the change in environmental parameters. The blood is redistributed and there are fluctuations in the hemodynamics and water-salt exchange indicators. There are also persistent changes in the blood system /7,10/.

Under normal terrestrial conditions, man finds himself in an extremely narrow zone of influence of such physical factors of the Earth as the gravitational field, electromagnetic radiation, the geomagnetic field, pressure and so on. Under spaceflight conditions, man goes beyond the limits of the terrestrial ecosphere and is exposed to the effect of completely new factors. The change in the gravitational field has the greatest effect on hemogenesis. It is a well known fact that the hemogenic function is the main factor of gravitational stability. The bone-marrow type of hemogenesis seen in mammals is phylogenetically caused by the necessity of maintaining a high exchange level and the increased oxygen requirement under the conditions encountered in a gravitational status [9].

The rearrangement of the hemogenic system that develops under the influence of weightlessness and other factors encountered during spaceflight is expressed in the changes in a number of hematological indicators [10,11]. The discovery of the intimate mechanisms of this process and the evaluation of its physiological significance require thorough morphofunctional research on the cellular and subcellular levels.

In this report we present the results of cytological investigations of the peripheral blood of cosmonauts who had completed 8-, 96- and 140-day flights. For the first time, data were obtained that characterize the degree of the full structural-functional value of erythrocytes and leucocyctes under these conditions. The results of the study of the morphofunctional properties of blood cells after extended flights (96 and 140 days) are particularly interesting. During these periods, several populations of erythroidal cells underwent differentiation from trunk cells to erythrocytes, while the basic mass of erythrocytes formed before the flight finished their life cycle. There was also a repeated exchange of thrombocytes and granulocytes and the population of short-lived lymphocytes was replaced.

In our work we investigated blood samples from cosmonauts who had completed 8-, 96- and 140-day flights. The samples were taken before the flights and at various times after the cosmonauts' return. As a control we used blood samples from healthy people with ages ranging from 25 to 45 years.

In our research we used the following methods: 1) the cytochemistry of blood cells -- fetal hemoglobin in the erythrocytes, alkaline phosphatase, myeloperoxidase and polysaccharides in the granulocytes, polysaccharides in the lymphocytes [8]; 2) interference microscopy of the erythrocytes [5]; 3) cellular analytical electrophoresis [2]; 4) preparative electrophoresis of the blood cells with subsequent analysis of the fractions on a "Coulter-Counter" cell counter [16]; 5) destructive electron microscopy [8].

As a result of the investigation of the cytochemical reactions for myeloperoxidase and askaline phosphatase, which characterize the functional state of the granular apparatus of nuclear-segment leucocytes, we discovered a number of changes in these indicators. After both brief and extended flights, the reaction for myeloperoxidase (the marker of the primary granules) remained at the control level, while for the cosmonauts who had made the 8-day flight, the reaction for alkaline phosphatase (the marker of the secondary granules) was discovered in a larger percentage of cells than normal in a number of cases (Table 1).

After the 96-day flight, the reaction for alkaline phosphatase in the granulocytes was heightened on the 7th day after landing. For the ship's

Table 1. Cytochemical Characteristics of Leucocytes in Peripheral Blood After Brief and Extended Spaceflight

Cytochemical reactions	Indicator	Flight																										Control (M±m),
		8-day												96-day				140-day										
		Times of investigation																										
		Pre-flight		After flight, days										After flight, days				Pre-flight		After flight, days								
				0-e				1-e				14-e		7-e		33-н				0-e		1-e		25-e		41-e		
		1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
Alkaline phosphatase	% of positive cells	52	67	84	61	29	28	70	72	26	36	30	31	94	68	2	76	40	29	72	30	62	39	49	31	30	26	35,7±2,1 (15—45)
	STsK	56	76	84	69	30	31	74	84	27	40	37	43	105	114	2	92	46	30	74	32	61	42	51	34	28	26	42,9±4,1 (6—80)
Myeloperoxidase	% of positive cells STsK	100 2,89	100 2,91	100 2,6_	100 2,9	100 2,95	100 2,9	100 2,88	100 2,97	100 2,96	100 2,90	100 2,92	100 2,89	— —	— —	— —	— —	100 2,83	100 2,88	100 2,94	100 2,91	100 2,88	100 2,88	100 2,90	100 2,94	100 2,94	100 2,96	100 2,9±0,07 (2,66—3,00)
Polysaccharides in granulocytes	% of positive cells STsK	100 2,85	100 2,89	100 2,98	100 3,00	100 2,91	100 2,86	100 2,94	100 2,91	100 2,86	100 2,71	100 2,92	100 2,88	— —	— —	— —	— —	100 2,82	100 2,91	100 3,00	100 2,97	100 2,99	100 2,98	100 2,94	100 2,95	100 3,00	100 2,99	100 2,94±0,08 (2,85—3,00)
Polysaccharides in lymphocytes	% of positive cells	65	78	97	70	36	10	98	86	42	16	76	57	—	—	—	—	36	48	60	80	67	76	58	70	54	81	14,6±0,1 (4—21)
	STsK	1,15	1,12	1,14	0,84	0,42	0,18	1,10	0,98	0,52	0,22	1,30	1,02	—	—	—	—	0,52	0,48	0,76	1,04	1,82	1,02	0,60	0,70	0,64	0,66	0,22±0,02 (0,15—0,35)

Note: Here and in Tables 2-4: 1 = ship commander; 2 = flight engineer; STsK = average cytochemical coefficient.

commander, on the 33d day the percent of granulocytes with a positive cytoplasm reaction dropped to 2 (see Table 1).

On the day of the landing after the 140-day flight, for the ship's commander we noted an increase in the number of cells with a positive reaction for alkaline phosphatase (72 percent). After 1 day this indicator dropped to 62 percent, and after 25 and 41 days it had decreased to 49 and 30 percent, respectively. For the flight engineer, the number of cells with a positive reaction remained at its initial level throughout all the stages of the investigation.

The cytochemical appearance of polysaccharides in the granulocytes' cytoplasm (the PAS-reaction), which reflects the level of a cell's energy reserves, was within the limits of physiological fluctuation for all those who were studied.

In the lymphocytes' cytoplasm, an increase in the PAS-reaction's intensity was seen after both short and extended flights. An interesting fact is that in a number of cases the percentage of PAS-positive lymphocytes had increased before the flight. For instance, for the ship's commander there were 65 percent PAS-positive lymphocytes before the flight, while on the day of landing after 8 days of flight this figure had increased to 97 percent (the norm is 4-21 percent), while for the flight engineer, the preflight figure of 48 percent increased to 80 percent after a 140-day flight.

The investigation of the state of the peripheral blood's erythrocytes included a determination of the erythrocytes' dry mass, a study of their electrophoretic mobility, preparative separation according to the surface electrical charge's value, and an investigation of the shape and surface architectonics of the erythrocytes' membranes.

The method of interferometric determination of the erythrocytes' dry mass makes it possible to obtain data on the percentage distribution of erythrocytes according to the amount of mass. On the average, the dry mass of erythrocytes consists of 95.5 percent hemoglobin. The other 4.5 percent is nonhemoglobin albumins, enzymes, polysaccharides, lipids, salts and other components. Since the synthesis of hemoglobin in erythroid cells ends at the reticulocyte stage, the hemoglobinization process of the bone marrow's erythroid cells can be judged by the distribution of the erythrocytes as a function of their dry mass.

For the cosmonauts, after the 8-day flight the distribution of the erythrocytes as a function of their dry mass reamined within the limits of the control figures (Table 2).

When cosmonauts who had completed extended flights were studied, the dry mass indicators also remained at the level of physiological fluctuation. The same phenomenon was also noted during the study of the blood samples taken on board the spacecraft on the 75th day of the flight. When blood

Table 2. Interferometric Determination of Dry Mass of Peripheral Blood Erythrocytes After Brief and Extended Spaceflight

Time of investigation	Percentage distribution of erythrocytes as a function of their dry mass (M±m)			
	20–29 pg	30–39 pg	40–49 pg	50 pg and more
Control group (10 healthy males)	16±2,5 (от 4 до 26)	63±3,0 (от 47 до 75)	22±2,6 (от 10 до 36)	1±0,8 (от 0 до 7)
8-day flight				
Preflight				
1	4	46	44	6
2	10	68	20	2
1	10	74	12	4
2	16	78	6	0
On day of landing				
1	8	64	22	6
2	12	72	14	2
1	10	54	36	0
2	28	60	12	0
1 day after flight				
1	10	68	18	4
2	4	68	24	2
1	8	56	32	4
2	20	60	20	0
14 days after flight				
1	6	44	48	2
2	18	46	32	4
96-day flight				
7 days after flight				
1	4	30	48	18
2	12	62	24	2
14 days after flight				
1	4	38	52	6
2	6	44	42	8
140-day flight				
Preflight				
1	4	54	38	4
2	4	68	24	4
In flight (75th day)				
1	8	64	24	4
2	4	74	22	0
On day of landing				
1	18	58	24	0
2	26	54	20	0
1 day after flight				
1	10	62	28	0
2	32	50	18	0
25 days after flight				
1	8	52	34	6
2	4	62	32	2
41 days after flight				
1	18	56	22	4
2	14	62	24	0

samples taken from the ship's commander 7 and 33 days after the 96-day flight were analyzed, there had been a shift in the indicators toward the higher values.

After the 140-day flight, an increase in the percentage of erythrocytes with small mass (in comparison with the preflight data) was noted for both cosmonauts on the day of the landing and the next day. However, these figures did not go beyond the limits of physiological fluctuation. In subsequent periods, the erythrocytes' dry mass values corresponded to the preflight indicators.

For all the cosmonauts, the percentage of cells containing fetal hemoglobin fell within the normal range of values (up to 1 percent). After the 96-day flight these indicators were 0.45 and 0.1 percent, while after the 140-day flight they were 0.1 and 0.2 percent.

For the purpose of making a quantitative evaluation of the magnitude of the erythrocytes' surface charge, their electrophoretic mobility (EFP) was investigated. It was established that the surface charge plays an exceptionally important role in the active life of a cell and is responsible for such processes as contact interaction, adhesion, aggregation and formation of the blood flow's structure. A cell's charge changes during its active life (different degrees of differentiation, a reduction in vitality, adsorption of different substances on the cell's surface and so on), thereby reflecting its biological status.

During the investigation of the erythrocytes' EFP (the calculations were based on 100 cells), it was noticed that -- on the average -- the preflight EFP value corresponded to the norm (1,079-1,131 $\mu m \cdot cm \cdot V^{-1} \cdot s^{-1}$). The day after landing from both brief and extended flights, there was a reduction in the EFP that was expressed in different degrees (0.965-0.994 $\mu m \cdot cm \cdot V^{-1} \cdot s^{-1}$). On the 3d day the EFP value had returned to its original level (1,035-1,138 $\mu m \cdot cm \cdot V^{-1} \cdot s^{-1}$). During subsequent investigations, the EFP values of the erythrocytes corresponded to the normal indicators.

In order to obtain an expanded description of the surface charge of the membrane of the entire population of erythrocytes, we carried out preparative electrophoretic separation of the cells. The suspension of erythrocytes was separated, with the help of preparative electrophoresis, into separate fractions, after which each fraction was analyzed with the help of a "Coulter-Counter" cell counter (the quantity and volume of the cells was calculated).

The investigations that were performed showed that 1 day after landing, the erythrocyte distribution curve had changed somewhat for both extended and brief flights. The factors noted were a slight lowering of the curve's peak and a relative increase in the number of cells in fractions with low and high mobility, as a result of which the distribution curve was compressed somewhat. This is indicative of a definite nonuniformity (by charge) of the cell population, despite the fact that the changes that were noticed did not not ge beyond the limits of physiological fluctuation (Figures 1-3).

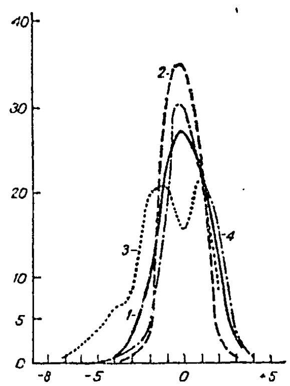

Figure 1. Erythrocyte distribution curves (in percentages) for blood samples taken after the 8-day flights. Here and in Figures 2 and 3: along the X axis -- numbers of samples with greater (-) or lesser (+) EFP relative to samples with the maximum cell content (sample 0); along the Y axis -- relative content (in percentages) of erythrocytes in samples 1 and 2, taken from the ship's commander 1 and 14 days after landing; 3 and 4 -- the same, for the flight engineer.

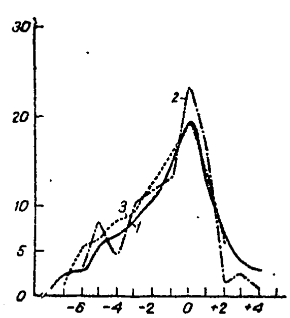

Figure 2. Erythrocyte distribution curves (in percentages) for blood samples taken after the 96-day flight: 1. control; 2, 3. 7th day after landing, for the ship's commander and flight engineer, respectively.

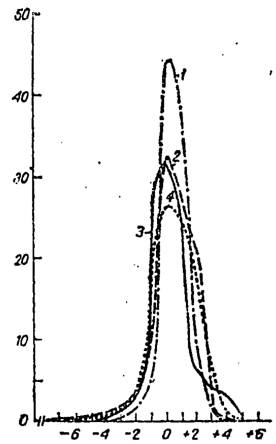

Figure 3. Erythrocyte distribution curves (in percentages) for blood samples taken after the 140-day flight: 1, 2. 1 and 25 days after landing, for the flight engineer; 3, 4. the same, for the ship's commander.

After brief flights, the curve of erythrocyte distribution with respect to EFP was normalized by the 14th day. The curve's peak was higher and there was less scattering of the erythrocytes among the samples. After the extended flights, the scattering of the erythrocytes among the samples dropped by the 25th day, although for the ship's commander after the 140-day flight there was a slight increase in the number of cells with lower mobility in the samples.

For the cosmonauts on the 96-day flight, an analysis of the erythrocyte distribution curves for samples taken 7 days after landing revealed a slight increased in the number of cells with higher EFP. It is possible that this is related to the increase in the number of reticulocytes that was observed at this time /1/.

Table 3. Average Erythrocyte Volume After 140-Day Flight

Subject	Erythrocyte volume, μm³		
	1st day	25th day	Normal
1	72,5	87,2	80—96
2	74,6	81,5	

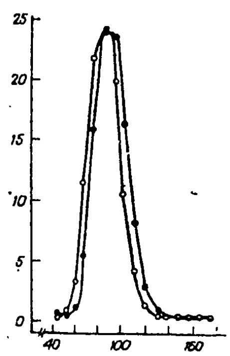

Figure 4. Average percentage content of erythrocytes in whole blood of cosmonauts after 140-day flight, as a function of the cell volume (25 days after landing).

A study of the average erythrocyte volume that was carried out with the "Coulter-Counter" analyzer showed that after extended flights, the volume of the cells is reduced somewhat on the 1st day after landing (Table 3). Normalization of the average volumes of erythrocytes took place by the 25th day after completion of the flight. After the 140-day flight, the increase in the average erythrocyte volume by the 25th day was most clearly expressed for the ship's commander. This is manifested in the graphs by a shift in the distribution curve toward the larger volumes (Figure 4).

For the cosmonauts who were on brief flights, no changes were observed in the erythrocytes' surface architectonics (in comparison with the preflight data) 1 day after landing (Table 4). The number of discocytes amounted to 87-89 percent; discocytes with a single protuberance -- 1.5-2 percent; discocytes with a ridge -- 3.5-4.5 percent. Discocytes with multiple protuberances, dome- and mulberry-shaped ones, discocytes in the shape of a deflated ball, and spherocytes amounted to a total of about 5-6 percent, while degeneratively changed discocytes constituted about 0.5 percent. These figures correspond to standard physiological parameters.

After the 96-day flight, 7 days after landing the basic cell mass was represented by discocytes. For the flight engineer, single cells with changed configurations were seen: in the form of a "drop," a "sickle," a "jellyfish." On the 33d day after landing, the erythrocyte distribution corresponded to the nomograph.

For the cosmonauts who had completed the 140-day flight, 1 day after landing we observed an insignificant increase in the number of dome-shaped erythrocytes and those in the shape of a deflated ball. After 25 and 41 days, no changes in the shape of the erythrocytes were observed (Figures 5-7).

A number of authors have shown that spaceflight is accompanied by certain changes in the most important hematological indicators. After extended flights, a reduction in the hemoglobin content, a decrease in the number of erythrocytes and reticulocytes and a change in the shape and size of the erythrocytes are observed persistently /1,7,10,11,15,17/. During the

Fig. 5. Erythrocytes in flight engineer's blood on first day after an 8-day flight: Biconcave discocytes in an SEM photograph (magnification = 4,000)

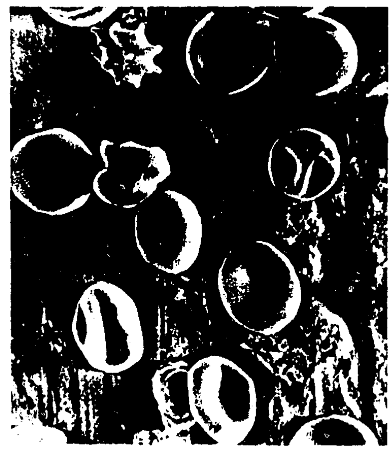

Fig. 6. Erythrocytes in ship commander's blood on first day after 96-day flight: In the SEM photograph there are biconcave discocytes, discocytes with a ridge, and erythrocytes in the form of a mulberry and a deflated ball.

Fig. 7. Erythrocytes in ship commander's blood on first day after a 140-day flight: In the SEM photograph there are biconcave discocytes and a domeshaped erythrocyte (magnification = 4,000).

Table 4. Form of Peripheral Blood Erythrocytes After Brief and Extended Spaceflight (Destructive Electron Microscopy), in Percentages

Type of Erythrocytes	Flight																		Control (M±m)
	8-day						96-day				140-day								
	Preflight		Postflight, days				Postflight, days				Preflight		Postflight, days						
			1-e		14-e		7-e		33-e				1-e		25-e		41-e		
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
Discocytes	84,5	89,0	88,0	89,0	89,0	89,5	59,0	52,0	81,5	83,5	93,0	87,0	89,5	86,5	90,0	92,0	95,0	96,0	85,05±10,1
Discocytes with 1 protuberance	2,0	0,5	2,0	1,5	1,5	3,0	6,0	6,0	2,0	5,0	1,5	2,5	1,0	2,5	1,0	1,0	1,0	0,5	3,32±0,21
Discocytes with ridge	5,0	4,0	4,5	3,5	3,0	1,0	9,0	6,0	2,5	2,0	1,0	3,0	2,0	3,5	5,0	3,0	3,0	2,5	5,68±0,54
Discocytes with multiple protuberances	1,0	1,0	2,0	1,0	0,5	1,0	8,5	7,5	6,0	3,5	1,0	3,5	0	0,5	0	0	0	0	3,48±0,5
Dome-shaped erythrocytes	3,5	3,0	2,5	3,0	2,5	1,5	1,5	3,5	2,5	1,5	2,5	2,0	4,5	3,0	2,0	3,0	0	0	1,25±0,15
Mulberry-shaped erythrocytes	0	0	0	0	0,5	0	5,0	3,5	1,0	0	0	0	0	0	0	0	0	0	0,36±0,14
Deflated-ball erythrocytes	3,5	2,0	0,5	1,0	0	0	3,5	3,5	1,0	1,0	0,5	1,5	2,0	2,5	1,0	1,0	1,0	0,5	0,53±0,14
Spherical erythrocytes	0,5	0	0	0,5	2,5	1,5	4,0	3,5	1,0	0,5	0	0	0	0	0	0	0	0	0,09±0,02
Degeneratively changed and degraded erythrocytes	0	0,5	0,5	0,5	0,5	0	3,5	5,0	2,5	2,5	0,5	0	1,0	1,5	1,0	0	0	0	0,19±0,06
Flat, drop-, heart-, bell- and jellyfish-shaped erythrocytes	0	0	0	0	0	0	0	9,5	0	0,5	0	0,5	0	0	0	0	0	0,5	0

process of organism readaptation in the postflight period, erythropoesis activation occurred, as evidenced by an increase in the number of reticulocytes and an increase in the erythropoetin level /11/.

The changes in the quantity and composition of the leucocytes are of a less stable type. In the first hours after landing, neutrophilic leucocytosis and eozinofilopeniye /sic -- possibly eosinophylogenesis/ are observed; they are related to the stress effects on the organism during the active sections of the flight. These changes are of a transient nature, and 24 hours after landing the number of leucocytes and the leucocytic formula return to their original values /10,14/.

For the interpretation of the changes in the hematological indicators, there is substantial interest in data on the metabolism of the cyclic nucleotides when acted upon by factors encountered during spaceflight. These are data on changes in the nucleotide excretion level and the tsAMF/tsGMF ratio /3,4/.

The complex cytological investigations of the peripheral blood of cosmonauts that we carried out on the cellular and subcellular levels showed that the total effect of spaceflight factors does not cause pathological displacements in the structural organization and functional properties of the blood cells.

After extended flights, some change in the activity of the nuclear-segment leucocytes' cytoplasmic granules is observed, along with an increase of the polysaccharide content in the lymphocytes' cytoplasm, which can be indicative of a change in intracellular exchange in response to the rearrangement of the hormonal profile /4,12/. The possibility that changes on the part of the lymphocytes are related to a certain extent to a reduction in the organism's immune resistance after extended flights has not yet been eliminated /7/.

The changes in the electrokinetic properties of the erythrocytes that we discovered are of a temporary and transient nature and are probably caused by stress reactions in the organism, since a reduction in EFP takes place only during the 1st day after landing. EFP normalization occurs by the 3d day after landing. The original profile of the erythrocyte distribution curves with respect to preparative electrophoresis is restored on days 14-25. Preparative electrophoretic separation of the erythrocytes reveals a definite relationship between normalization of the average erythrocyte volumes and the charge magnitude distribution curves.

Some fluctuations in the ratio of erythrocytes containing large and small quantities of hemoglobin are seen, both on the 1st day after landing and in the dynamics of the subsequent readaptation. The appearance of a population of erythrocytes with an increased hemoglobin content during this period can be regarded as a compensatory reaction.

Investigations of the shape of erythrocytes in blood samples taken from American astronauts revealed that the membranes of erythrocytes in samples taken during a flight were serrated /18/. These changes disappeared after the astronauts landed.

The results obtained by us show that after flights lasting 8, 96 and 140 days, no gross changes in the erythrocytes' surface architectonics are observed. When the cosmonauts who had completed the 96-day flight were studied, solitary changed forms and a redistribution of the ratio of different erythrocyte forms normally encountered had taken place. These indicators were normalized on the 33d day after landing. It should be mentioned that these changes were not noted after the 140-day flight, which can be explained by the more rational utilization of prophylactic measures and an improvement in the program for physical training during the flight /7,13/.

On the whole, the data obtained during the complex cytological investigation of the erythrocytes and leucocytes in the peripheral blood of cosmonauts who had completed 8-, 96- and 140-day flights showed that the changes in the cells' structural-functional properties are not of a pathological nature, but are an expression of the adaptational and readaptational processes in the hemopoesy system

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SPACE APPLICATIONS

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SPACE GEODESY AND QUESTIONS ON THE THEORY OF GEODESY

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/Article by Professor M.M. Mashimov, doctor of technical sciences, Military Engineering Academy imeni V.V. Kuybyshev/

/Text/ The space age began in the USSR, on 4 October 1957, with the launching of the first artificial earth satellite. There arose a practical need for the creation of a geocentric system of geodesic coordinates, the construction of a mathematical model of terrestrial gravitation that is adequate for the earth's external gravitational field, and the determination of the spatial position of artificial cosmic bodies. With the appearance of artificial earth satellites and spacecraft (AES), for the first time geodesy became capable of formulating experiments and performing geodesic work on a planetary scale, using the cooperative efforts of many countries. Space geodesy was born. This is the branch of geodesy that solves basic geodesic problems with the help of observations of the position of cosmic objects and their movement in the gravitational field formed by earth and the moon.

Projects for AES observations received extensive development within the framework of collaboration among the socialist countries' academies of sciences. This work was begun in 1961, on the initiative of the USSR Academy of Sciences' Astrosovet /Astronomical Council/ and GAO /Main Astronomical Observatory/ in Pulkovo. International cooperation in the area of space geodesy is continuing to expand. In 1968-1969, USSR and Soviet-African stations with AFU-75 and SBG cameras, together with American, French and English stations, took part in international observations of the PAGEOS AES in order to establish geodesic links between Europe and Africa /1/. Soviet stations in Zvenigorod, Riga and Uzhgorod made observations as part of the International Experiment on Satellite Geodesy (JSAGFX), in which 14 countries participated.

The Soviet radioastronomers L.I. Matveyenko, N.S. Kardashev and G.B. Sholomitskiy advanced the idea of long-base radio interferometry, in 1965.

Projects for determining the moon's position with the help of lasers were carried out at the USSR Academy of Sciences' Physics Institute under the leadership of Yu.L. Kokurin. The first laser pulse reflected from the moon's surface was received at the USSR Academy of Sciences' Crimean Astronomical Observatory in 1965, and it enabled the distance to that body to be measured.

Radio position finding for the planets closest to the earth, which work was performed under the guidance of Academician V.A. Kotel'nikov, produced basic results that are more accurate by a factor of 35 than data obtained by optical observations and that were used to determine the size of the universe.

Scientists at MIIGAiK /Moscow Institute of Engineers of Geodesy, Aerial Surveying and Cartography/, under the leadership and with the personal participation of Professor V.D. Bol'shakov, made a large contribution to the solution of the problem of the geodesic and topographic use of ISZ's and KA's.

Significant contributions to the development of space geodesy were also made by A.A. Mikhaylov, Zh.S. Yerzhanov, I.D. Zhongolovich, A.G. Masevich, V.K. Abalakin, K. Arnol'd, Yu.V. Batrakov, Ye.G. Boyko, M. Bursha, G. Veys, V.S. Gubanov, A.A. Izotov, U. Kaula, I. Kozai, K.V. Malets, P.P. Medvedev, L.P. Pakhmutov, L.P. Pellinen, I.Ya. Pleshakov, K. Popovich, V.F. Proskurin, P.Ye. El'yasberg, O.S. Razumov, V.S. Troitskiy, G.A. Ustinov, G.A. Chebotarev and other scientists in the USSR and abroad who have worked fruitfully in this new scientific field.

Satellites close to the earth are disturbed more by the earth's gravitational field than by the moon's. For example, an AES at an altitude of 1,000 km has an orbital perturbation caused by the earth's polar compression that is greater by a factor of 1 million than the perturbation caused by the moon. This circumstance is the explanation for the fact that the polar compression has now been determined extremely reliably on the basis of AES observations. Observations made from only the second Soviet satellite, in 1957, made it possible to determine the earth's polar compression with a degree of accuracy that was achieved with classical methods only after astronomical-geodesic and gravitational data had been accumulated for more than 100 years. Using AES observations, the polar compression has now been determined extremely reliably, with an error corresponding to the error of the difference in the major and minor semiaxes of the terrestrial ellipsoid -- on the order of 0.3 m. By processing the data from observations made by a large number of AES's over an extended period of time, an annual variation in the second harmonic of the J_2 coefficient of the earth's potential was discovered.

Having evaluated the J_2 parameter reliably, it is possible to determine a standard ellipsoid that represents the gravitational model in the first approximation.

In many practical instances, such an approximation is sufficient if the standard ellipsoid with a mass equal to that of the earth approximates the planetary geoid's shape and dimensions in the best manner possible.

The determination of the parameters of a standard ellipsoid having the earth's center of mass as its origin and a quasiadequate planetary geoid is one of the problematical goals of geodesy.

In 1961, A.P. Aksenov, Ye.A. Grebennikov and V.G. Demin proposed the idea of using the generalized problem of two immobile centers for computing ... intermediate orbits of AES's, representing the geogravitational potential (in the first approximation) as follows:

$$V=\frac{fM}{r}\sum_{n=0}^{\infty}J'_n\left(\frac{a}{r}\right)^n P_n(\sin\varphi);$$

$$J'_n=\frac{1}{2}\left(\frac{c}{a}\right)^n\left[\left(1+\sqrt{-1}\,\sigma\right)\left(\sigma+\sqrt{-1}\right)^n-\right.$$
$$\left.-\left(1-\sqrt{-1}\,\sigma\right)\left(\sigma-\sqrt{-1}\right)^n\right].$$

In this case, an AES's flight equation, is integrated in quadratures /2/.

The first approximating expressions for the potential of the earth's attraction in the theory of AES flight that permit integration in quadratures were proposed in 1959 and 1960, in works by T.P. Vinti /3/ and M.D.Kislik /4/. In 1958, R. (N'yuton) attempted to use the classical problem of two immobile centers of actual masses to study ISZ motion. Using a solution method different from N'yuton's, G.G. Koman /5/ tried to show that the intermediate potential would contain three zonal harmonics of the potential of the moon's attraction.

In 1977, V.F. Yeremeyev and M.I. Yurkin discussed the determination of the parameters of an AES in a field of two immobile centers and the temporal changes in these parameters by using laser and Doppler observations, photographs of satellites against the background of stars, and measurements of AES altitudes over the ocean.

The harmonic coefficients and anomalies in the force of gravity that have been derived from satellite observations can be compared with the same data as determined by terrestrial measurements. By representing an anomalous field discretely and using the well known method of adding the matrices of normal equations, it is possible to determine the anomalous field's parameters by the joint processing of terrestrial and satellite data. In connection with this, the average values of gravitational anomalies determined from terrestrial measurements with an error on the order of 1-2 milligals can be regarded as errorless, since satellite observations are not yet made with such accuracy. In any case, by assigning weights to the corresponding values of average gravitational anomalies or quasigeoid altitudes, as determined by the terrestrial and satellite methods, it is possible to solve correctly the problem of the joint equalization and derivation of the anomalous part of the geopotential.

Rapid progress has been made in facilities for measuring the altitudes of AES's above the ocean surface. It is expected that altitude measurement accuracy will be on the order of 0.3 m in the next few years. Assuming a known AES orbit, measured altitudes can be used to determine the geoid's profile; assuming a known geoid shape, they can be used to define a satellite's orbit more precisely. It is also possible to have a general case of the use of such measurements where the satellite alignment equations are solved jointly with equations representing photographic, laser, range-only radar and Doppler measurements.

With the introduction of the satellite alignment method, our previous ideas that the general features of the earth's gravitational field are determined more reliably on the basis of the orbital perturbations of near-earth satellites, while terrestrial measurements of gravity give a better picture of its details will be true only in part and only for the continental areas. As far as our planet's watery outer layer -- which is more than 70 percent of its surface -- is concerned, satellite alignment data will be used overwhelmingly.

In the future, a "satellite-satellite" system will be used to study the fine structure of the earth's gravitational field. By registering short-period variations in AES speed on the order of 0.05 mm/s or less, Doppler measurements in a "satellite'satellite" system will supply valuable information for the detailed study of the geopotential's parameters. Two versions of the "satellite-satellite" system can be used. One assumes the use of satellites circling the earth in the same low orbit. In this case, the variations in the differences between their speeds over a fixed interval of time give sufficiently complete information about the short-period perturbations in the orbit of these satellites that are caused by anomalies in the earth's field. In the second variant it is possible to use a "near-earth satellite-geostationary satellite" system. In this case, the variations in the differences between the speeds of the low and geostationary satellites will represent the short-period perturbations in the low satellite's orbit, since short-period errors in the geostationary satellite's orbit are negligibly small and can be ignored.

Representation of the geopotential in every detail and with high accuracy is a practical problem for the near future. Geodesy will have at its disposal satellites with orbits that will be known with high accuracy. Laser technology is being developed rapidly. It is expected that in the future, laser observations of satellites will make it possible to determine the coordinates of terrestrial points with an accuracy of several centimeters. The satellite will be the carrier of coordinates and time. Not only geodesy, but also other earth sciences and technological branches will have a powerful instrument for solving their own scientific and practical problems.

Models of the earth's external gravitational field derived from a combination of terrestrial and satellite data are already quite detailed and yield good estimates, and the first attempts have been made to use them to compute moments of inertia, the secular movement of the poles, and the orientation of the axes of the principal moments of inertia /6-8/. In /8/, materials obtained with the GEM6 satellite were used to derive the following parameters for the earth's dynamic shape:

$$A_0 = 8.01602055298 \cdot 10^{44} \text{ g-cm}^2$$
$$B_0 = 8.01619595712 \cdot 10^{44} \text{ g-cm}^2$$
$$C_0 = 8.04242790440 \cdot 10^{44} \text{ g-cm}^2$$
$$\alpha_p = 0.0016376320$$
$$\alpha_e = 0.0000109407$$

The ellipsoid of inertia has less polar and equatorial compression than the gravitational ellipsoid. Relative to the pole of inertia, the conventional pole is displaced 25 m along the 105°09' East Longitude meridian.

At the present time, the gravitational model of the planetary body is in the form of an infinite series of spherical functions. The expansion of the planetary body's potential into an infinite series of spherical functions has three substantial shortcomings:
1. The difficulty of evaluating the common term and the necessity of using a large number of harmonics because of the series' slow convergence.
2. When refining the model of the gravitational potential, every time it is necessary to compute the entire set of coefficients of expansion by solving poorly defined equations of a high order.
3. Representation of the potential in the form of a series of spherical functions engenders resonance effects.

Therefore, it is necessary to look for new methods of representing the geogravitational potential. One of the promising methods is a model of point masses, the computation of the summary potential of which is an elementary problem.

The representation of the gravitational potential of the planetary body of the earth, the other planets and the moon through high-order moments of inertia has become a matter of practical urgency. Knowing the full spectrum of moments of inertia, it is possible -- in the first place -- to solve correctly the problem of representing a planetary body's potential in terms of the potential of point masses and, in the second place, to obtain valuable information about the distribution and displacement of the masses in the planetary body. The numerical values of the earth's moments of inertia up to the eighth order, inclusively, as computed by us on the basis of data gathered by the GEM6, yield encouraging results for the possibility of solving the two contemporarily practical problems listed above.

The uncertainties in the geodesic conclusions about the distribution of masses in the earth's body can be resolved by using the parameters of the geoseismic field. They can be supplemented with the parameters of the geomagnetic and geothermal fields. Considerably more detailed and accurate three-dimensional models of the structure of the earth's crust and upper mantle can be constructed if geodesic data on the earth's external gravitational field and high-order moments of inertia are used in conjunction with the parameters of the geoseismic, geomagnetic and geothermal fields.

The theory of a three-dimensional model of the earth's metrics is of fundamental importance for all sciences concerning the earth. Future progress in geodesy, geophysics, geodynamics, geotectonics and geology is coupled with the solution of this problem. In view of this, let us turn our attention to the necessity of determining those parameters of a triaxial ellipsoid that are needed in order to study large irregularities in the distribution of masses and their spatial location in the earth's body. It is difficult to overestimate the importance of solving these problems for all earth sciences, including geodesy.

After obtaining reliable data on the distribution of masses in the earth's body, it is possible to obtain a rigorous solution for the problem of the reduction of astronomical-geodesic and gravimetric measurements. This also means the possibility of making a rigorous determination of the standard planetary surfaces and computing orthometric heights accurately. As never before, geodesy will be close to the other sciences that study the internal structure of planets.

In both theory and practice, there are very promising methods for constructing a gravitational model of a planetary body and for the discrete representation of the heights of elementary areas of the geoid above the normal standard ellipsoid.

Following Lame's work (1839), A. Poincare used ellipsoidal functions to investigate the equilibrium shapes of rotating bodies of a liquid mass (1902). In deriving the normal potential of a triaxial earth, Professor D.V. Zagrebin (1948, 1976) also used Lame's functions.

The utilization of Lame's ellipsoidal functions is useful not only for the possibility of achieving an elegant solution for Dirichlet's problems for an ellipsoid, but should also yield more efficient expansions of the potential (from the viewpoint of convergence) than the use of spherical functions. Besides this, its first approximation is more adequate for a planetary geoid's potential than the first approximation in the expansion of the potential by spherical functions. Considering the needs of other earth sciences and considerable practical work that uses the parameters of large geoid waves, the development of methods for expanding the potential with the help of ellipsoidal functions can be regarded as one of geodesy's urgent problems.

The modeling of the gravitational potential with the help of a discrete representation of the heights of elementary areas of the geoid is a promising direction in the general problem of creating an information bank of geodesic data on the earth and its surface.

The diversity of spacecraft as far as their purpose and daily practical use is concerned is helping us advance toward our goal of creating different reference models of the earth's external gravitational field, each of which makes it possible to construct a theory of motion for a certain class of spacecraft in the best possible fashion.

In the near future, geodesy will also have at its disposal that powerful tool the radio interferometer. By using radio interferometers with large (1-7 percent of the earth's radius), planetary (1-2 earth radii) and cosmic (20 or more earth radii) base lines, it will be possible to obtain a successful solution for the problem of the fundamental terrestrial and stellar coordinate system for our era and the problem of the metrics of ce[illegible]rial and near space.

Secular, periodic and irregular movements of the earth's poles and the relative motions of large blocks of the earth's crust can be determined on the basis of variations in the topocentric coordinates of radio interferometry base lines. Observations with radio interferometers located on different platforms in the lithosphere can be used to determine the platforms' relative motion, while observations made with several radio interferometers on a single lithospheric platform can be used to determine its deformation and rotation. Nonuniformity in the daily rotation of the earth will be determined with high accuracy. A system of radio interferometers that encompasses the globe will be a powerful tool for geodynamic research.

New horizons are being opened for geodesy by light position finding with angled reflectors that have been placed on the moon. The moon, which always keeps the same face turned toward the earth, is a convenient cosmic object for geodesic observations because of the slow change in the equatorial coordinates of points on its surface. With the help of a telescope that is continually tracking a reflector, it is possible to integrate the signals of a whole series of pulses, within the framework of which changes in the topocentric distance ρ of a lunar reflector are allowed for with great accuracy.

Laser observations of a lunar reflector produce a system of equations into which -- besides the measured topocentric distances ρ -- enter the geocentric coordinates of the observatories and the moon, the selenocentric coordinates of the lunar reflector and the parameters of the moon's libration.

Over small intervals of time, it is possible to distinguish a periodic component in the increments of topocentric distance:

$$\Delta\rho = -2\frac{r}{\rho} D \cos\delta \sin(\alpha - S - \lambda)\,\Delta s,$$

which component is caused by the earth's daily rotation, the amplitude and phase of which correspond to the radius D of the diurnal circle and the longitude λ of the observatory.

The requirements for the accuracy of the estimate of the moon's geocentric radius r are not high, since the ratio D/r is a small number.

The effect of an error in right ascension α can be reduced to a minimum by observing a reflector of a symmetrical meridian. The effect of an error in declination can also be lessened methodically by isolating it from a series of monthly observations.

It is expected that the accuracy of the determination of an observatory's diurnal circle and the differences in the longitudes and distances from the equator of two observatories will be comparable to the accuracy of the measurement of the topocentric distance.

Thus, light position finding with lunar reflectors makes it possible to create a network of fundamental base lines that connect the terrestrial observatories. Using the variations in the parameters of these base lines, it will be possible to study the secular, periodic and irregular movements of the earth's poles and changes in the relative position of points on its surface.

It will also be possible to solve these fundamental problems for the moon and to refine the theory of its motion.

Radio engineering measurements of the motion of spacecraft launched toward the planets nearest to earth make it possible to calculate the earth's mass extremely accurately and, consequently, define the geocentric gravitational constant more precisely. In recent years the most reliable determinations of the geocentric gravitational constant have been based on observations of spacecraft launched toward other planets. The geocentric gravitational constant, as determined as the weighted average of 19 determinations, has the value $fM = 398{,}601.2$ km^3/s^2, with a relative average mean-square error of 1:2,000,000.

The accumulation of observations from light position finding of the moon with the help of lasers makes it possible to solve the problem of determining fM, using the well known relationship

$$fM = \frac{n_{☾}^2 (1 + \nu_{\odot})^3}{1 + \mu} a_{☾}^3,$$

which follows from Kepler's Third Law. In this formula, $n_{☾}$ = average motion of the moon; $\nu_{\odot}$ = a parameter that allows for perturbation caused by the sun; μ = ratio of the moon's mass to the earth's mass; $a_{☾}$ = major semiaxis of the moon's variation orbit.

The processing of materials from light position finding of the moon and data from other experiments made it possible to improve the theory of the moon's motion substantially, refine the value of fM, and reliably determine the selenocentric location of the lunar laser reflectors.

On the basis of observations made at the Macdonald Observatory (United States), the value

$$fM = 398600{,}48 \quad \text{km}^3/\text{s}^2$$

has been determined, giving the observatory's geocentric location.

Radio engineering range-finding and Doppler measurements have a scale distortion and are scaled by data from the laser location of the moon and long-base radio interferometry. Besides this, the speed of light in a vacuum has been defined more precisely. At the present time, the following value is recommended for it:

$$c=299792{,}458 \text{ km/s}.$$

Allowing for this, the value of fM -- as determined from spacecraft observations with a very high degree of internal convergence -- has been scaled and the value fM = 398,600.5 km^3/s^2 is recommended.

Dynamic satellite trilateration in combination with precisions measurements of the topocentric equatorial coordinates of AES's and satellite leveling is a highly promising area. The greatest promise is offered by precision laser and radio-interferometric satellite trilateration based on quasisynchronous measurements of "earth-satellite" and "satellite-satellite" distances. Over a short period of time, it is possible to predict -- with high accuracy -- the orbits of AES's used in dynamic satellite trilateration. In connection with this, it will also be possible to construct planetary and continental geodesic networks with accuracy in the centimeter range.

Geodesic observations of AES's, the moon, spacecraft and radio interferometers with large, planetary and cosmic base lines, together with data supplied by terrestrial geodesy, astronomy and gravimetry will make it possible to find new solutions to the problems of studying the physical, gravitational and dynamic shapes and the external gravitational field of the earth, establishing a planetary, geocentric system of geodesic coordinates for each epoch, studying the the displacements of the earth's poles and center of mass, determining the location of points on the earth's surface and in near space in a continental or planetary system of coordinates for this era, finding geodesic substantiation for the strudy of nature and the mapping of separate continents and islands and the entire surface of the earth, and studying the movement of the earth's crust and other processes caused by the life of the earth, on the whole, as a planet.

The problem of a planetary, geocentric system of geodesic coordinates and the determination of the physical, gravitational and dynamic shape of the earth for this era are now the main scientific and technical concerns of geodesy.

The problem of studying the gravitational potential of a field is essentially a physical one, as are the study of the seismic, magnetic, geothermal and other physical fields of the earth. However, considering the entire importance of the problem of the geogravitational potential for geodesy itself, pluse the fact that it is solved by geodesic methods (while the parameters of the earth's external gravitational field and shape are determined by processing the same data and using them jointly), the problem of studying the earth's external gravitational field should be regarded as a geodesic one. The requirements of modern practice are such that the coordinate and gravitational problems should be formulated and solved jointly, as a common problem concerning the earth. Only if this is done will we be able to model the earth's metric in the best possible fashion. The ever increasing requirements for original astronomical-geodesic data have raised the question of allowing for the anisotropy of space around the earth, the moon and the other planets.

The theoretical problem of geodesy should now be formulated and solved in such a fashion that a noncontradictory model of the geogravitational potential that is adequate for the earth's actual potential for that era for which the coordinate system has been established corresponds to the planetary system of geodesic coordinates. The problem of the consistency of the model of the earth's external gravitational field and the planetary system of geodesic coordinates has moved to the front as the fundamental therotical and practical problem of geodesy.

No less important is the problem of studying the proper motion of points in the planetary, continental and regional geodesic networks and temporal variations in the characteristics of the earth's external gravitational field, as well as the formulation of different theories and hypotheses for the formulation and solution of this important problem.

The first stage in the solution of these fundamental problems must be the creation of a network of astronomical-geodesic observatories at which an entire complex of precision, terrestrial, astronimcal-geodesic and gravitational measurements are made, along with observations of ISZ's, KA's, the moon and natural and artificial radio sources. The astronomical-geodesic observatories will secure the continental and planetary system of geodesic coordinates for each epoch.

The urgency of these problems is explained, in the first place, by the rapid technical and scientific progress in the field of the geodesic study of the earth and near space, the improvement in the accuracy and increase in the volume of measurements, and the possibility of repeating measurements frequently and then obtaining a reliable estimate of the parameters of the earth's shape and external gravitational field.

In the second place, there has been an acute tightening of the practical requirements for the system of geodesic coordinates that is fixed on the earth by points in the geodesic network and for the parameters of the earth's shape and external gravitational field. The proper motion of each point in the geodesic network should be the object of a study; modern practice already requires a system of coordinates for each era, and such a system of coordinates will be necessary for the solution of everyday, practical problems in the near future for not only geodesy, but also for the other fundamental sciences and branches of technology.

The problem of studying the planetary evolution of the earth is in the forefront of geodesy. The movement of the earth's crust, displacement of lithospheric slabs, changes in shore lines and sea and ocean levels, irregularities in the earth's rotation, the displacement of its poles and center of mass -- all of these complex phenomena caused by planetary processes in the life of the earth must be taken into consideration when processing astronomical-geodesic and gravimetric measurements and observations of cosmic objects and are subject to study not only in geophysics, geology, oceanography, astronomy and gravimetry, but -- to a great extent -- in geodesy. The spectrum of geodynamic phenomena (planetary, which apply to the entire planet and in the interpretation of which the earth is replaced by some ideal model; large scale, which are manifested within the limits of a continent or a lithospheric slab; local, which apply to areas extending for less than 100 km).is extremely varied, and the phenomena themselves are quite complicated. As a rule, all the phenomena (except for the planetary ones) are related to processes taking place in the upper mantle and the crust. The processes occurring in the upper layers of the crust and on the earth's surface (including technogenic processes) are related to human activity and give rise to local phenomena. However, large-scale and regional phenomena that manifest themselves inside limited zones on the boundaries of crustal blocks are frequently difficult to distinguish from local phenomena.

Different phenomena frequently manifest themselves as changes in the same terrestrial parameter. For example, changes in the parameters of the earth's gravitational field and vertical movement of the crust affect variations in the force of gravity. The heights of points change because of the crust's vertical motion and changes in the slopes of standard surfaces. A variation in latitude reflects movement of the poles, a change in the slopes of standard surfaces and horizontal motion of the crust.

In order to study the dynamics of the earth, it is necessary to have highly accurate measurements, the frequency, duration and spatial scope of which it is necessary to establish in such a fashion that all the geodynamic phenomena can be evaluated in the best possible manner.

The full spectrum of planetary, large-scale, regional and local geodynamic phenomena can be studied by making combined use of terrestrial astronomical-geodesic and gravimetric measurements, satellite observations, light position-finding of the moon and long-base radio interferometry. By using extensive and periodically repeated observations that tie together the lithspheric slabs and the individual continents, it will be possible to study many planetary phenomena. Geodynamic ranges (polygons), the number of which is increasing, should be special objects of observation. Terrestrial and space geodynamic observations should be made according to special programs that produce long series of highly accurate measurements that show the effects of secular, long-period, short-period and irregular geodynamic processes.

Once there is an extensive network of astronomical-geodesic observatories that covers the entire globe and is quite dense in some areas, in which laboratories an entire complex of measurements will be made, it will be possible to count on further progress in the solution of the problems of geodynamics and of geodesy as a whole.

With time the geodynamic theories will become definitive in the sense of planetary geodesy, in the development of programs for astronomical-geodesic and gravimetric work, and in the development of programs of observations for cosmic objects. The study of contemporary movements of the earth's crust that has been carried out so successfully in the USSR will make a decisive contribution to the development of the neomobilists' new theory of global geotectonics.

In the last 10-15 years, when there was a sharp increase in the volume of geological and geophysical work that was done (particularly in the water areas of the world ocean), there appeared data indicative of horizontal movements of both the continental and oceanic blocks of the earth's crust. The positions of the neomobilists' new concept, which hypothesizes large-scale horizontal displacements of the lithospheric slabs along the surface of the asthenosphere, are gaining more and more strength. According to the neomobilists' ideas, continents move, the theory of global geotectonics is of prognosticative value, and it can be used in all sciences concerned with the earth. Therefore, the geodesic study of horizontal movements has now acquired a special significance, whereas previously only vertical movements of the crust were studied. From the geodesic and geophysical viewpoints, the vertical and horizontal movements should now be regarded as orthogonal components of the lithosphere's spatial movement with respect to time. The development of a theory and methods for geodynamics has become one of the pressing problems of contemporary geodesy. In connection with this, the methods of space geodesy are making a basic contribution to the solution of the problems of geodynamics. It should be kept in mind that geodesy must furnish many branches of science and technology with data on the earth's planetary evolution (the movement of the earth's crust and poles, variations in the earth's gravitational field and speed of rotation, continental drift and changes in the continents' shore lines, and other phenomena), as well as materials for predicting and evaluating the consequences of a change in the masses that are local in the earth's body and planetary in scope in its atmosphere. Data on temporal changes in coordinates and the gravitational field, for both separate sections, regions and continents and the planet as a whole, and the parameters of the proper motion of points in the continental or planetary geodesic network are extremely valuable material for studying the physics of the earth, geological structures and geotectonic processes. Knowledge of the internal structure of the earth and the processes taking place inside it will make it possible to optimize geological predictions and the exploration of the earth's depths, study earthquakes in their formative stage (and other tectonic processes), and evaluate the possible consequences of these menacing natural phenomena and even prevent them. Thus, geodesic determinations that are related to the reference geodesic network, the geocentric system of coordinates and the earth's shape and gravitational field should be reduced to a certain epoch, with due consideration for the movement of the poles, variations in the earth's rotational speed, movements of the earth's crust, and other effects. This urgent problem of geodesy can be solved jointly by using all measurements supplied by terrestrial and space observation facilities.

One complicated problem is the development of a theory of the mathematical processing of measurements made on regional, continental and planetary scales. Another urgent problem is the development of rigorous theories of the processing of measurements that make it possible to evaluate all unknown parameters in the best possible manner and to optimize the program for the measurements themselves, formulate requirements for facilities and methods for performing the work, and make effective use of the capabilities of computer centers. It is also necessary to create a powerful geodesic bank that consists of a series of departments for each separate area in geodesy.

The quasi-inertial stellar system of coordinates continues to satisfy geodesy. As the accuracy improves, we will unavoidably have to take its quasi-inertial nature into consideration. In the forefront are problems concerning the inertial system of coordinates, the fundamental astronomical constants, and the measurement and keeping of time. It is necessary to stimulate the creation of basic catalogs of the positions of remote natural objects in space and the development of fundamental astronomy in both the optical and radio-wave spectra.

Further progress in geodesy now depends on the level of our knowledge of the earth's atmosphere and ionosphere, solar-lunar tides, and the internal structure of the earth.

In the study of these questions, a special place will be occupied by large satellite telescopes, special astrometric satellites, a ramified network of radio telescopes, and latitudinal, gravimetric, level-gauge, seismic, magnetometric, aerological and meteorological stations.

In conclusion let us mention that as the role of applied geodesic problems expands in geodesy as a whole, the theories of the coordinate-gravitation problem and the geodynamic processes studied in each era are becoming ever more urgent. This trend in the development of geodesic science will be even more overwhelming in the near future.

The development of a theory of the construction of mathematical models of the metrics of earth and near space and geophysical fields, along with the intepretation of experimental data with the help of such models has become a key problem in geodesy.

Since it studies the metrics of nature on regional, continental, planetary and even cosmic scales, modern geodesy has become one of the fundamental natural sciences focusing on earth and near space.

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SCIENTIFIC PROBLEMS IN SPACE GEODESY

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/Text/ Space geodesy is the youngest and, apparently, most rapidly developing division of geodesic science, but it is important to mention that the scientific problems of space geodesy coincide completely with those of geodesy as a whole. In general, any modifiers of the word "geodesy" characterize either the investigative method or the objects of the application of geodesic knowledge. Otherwise we would have a conglomerate composed of a set of geodesies that are not united by common scientific problems and goals. Therefore, space geodesy should be defined as that division of geodesy in which the basic scientific problems are solved with the help of observations from artificial heavenly bodies or by processing the results of measurements made directly on board spacecraft. This definition describes the scientific method of space geodesy. It is precisely this method that makes it possible to obtain effective solutions for a whole series of scientific problems in geodesy, the primary ones of which are:
determining the fundamental geodesic constants;
refining our model of the earth's external gravitational field and shape;
formulating global geodesic spatial networks.

Space geodesy also solves these same problems relative to other bodies in the solar system, with special emphasis on the Moon, Mars and Venus.

An extremely important problem in space geodesy is the coordinate-temporal correlation of the results of space surveying that serve as the basis for the mapping from space of the Earth and other planets in the solar system, as well as investigations of the earth's natural resources. Radical geophysical conclusions are also being reached on the basis of data from space geodesy, and in connection with this special features of the earth's gravitational field have been definitely linked to the structure of the upper mantle, while the high-order harmonic coefficients in the expansion of the geogravitational potential with spherical functions are being correlated with the corresponding coefficients in the expansion of the heights of the earth's relief. The Love number k_2, which characterizes and elastic properties of a planet, is of importance for the physical study of planets. Space geodesy methods make it possible to obtain a reliable definition of the Love number. Another extremely important matter is the study of temporal variations in the force of gravity, information about which is obtained be satellite observations. They are important indicators of several features of the earth's internal structure, both now and in the past. In the future, highly accurate space networks that encompass the entire surface of the globe and that have been repeatedly observed and equated will make it possible to establish quite accurately the nature and special features of continental drift, so that the scientific and practical consequences emanating from this can be determined. It is space geodesy that will be used to obtain a definitive solution of the problem of the movement of the earth's poles, the circumstances of its daily rotation and, in particular, the problem of the slowing down of the earth's rotation.

Space geodesy methods can be used to determine the value and nature of even more general cosmogonic effects that are related (for example) to relativistic physics. For instance, the secular accleration of the moon's longitude (equal to $-16''T^2$, where T is given in centuries) that has been discovered through extended observations can be regarded as the result of secular diminution of the universal gravitational constant f:

$$\frac{\Delta f}{f} = (-0{,}9 \pm 0{,}3) \cdot 10^{-8} \text{ per century.}$$

The use of laser position finding of the moon makes it possible to define the parameters of its orbital motion more accurately, thereby enabling us to achieve a more accurate determination of this effect, which has been confirmed by modern gravitational theories.

On the one hand, progress in the development of space geodesy methods is related to the continuous improvement in the accuracy of observations of spacecraft, the moon and extragalactic radio-frequency emission sources (quasars), and on the other, to the improvement in its theoretical concepts, the use of modern mathematical methods, and the increase in the operating speed, memory volume and other characteristics of computers.

The present state of measurement technology makes it possible to realize an extremely broad range of different parameters that can be used to solve the problems of space geodesy. In accordance with the physical principles on which the structure of specific measurement systems are based, they can be divided into radio engineering, optical, gravitational, magnetic, acoustic, radiation and other types of systems.

The structural design of existing measurement systems makes it possible to change from primary parameters to others that make obvious geometric sense, such as (for example) distances, directions, velocities and their derivatives. The values obtained as a result of this form a system of secondary parameters, and in connection with this the same secondary parameter -- direction, for example -- can be determined with the help of different equipment.

Under these conditions there arises the problem of choosing equipment that will insure the determination of secondary parameters with the degree of accuracy needed for the solution of the contemporary problems of space geodesy, as well as having the best operational capabilities in the sense of dependence on the external physical conditions and the complexity of allowing for external factors (refraction, atmospheric turbulence, the effect of the ionosphere and the earth's magnetic field, solar radiation and a number of other factors). It should be mentioned here that the solution of the fundamental problems of modern space geodesy now requires measurements with exceptionally high accuracy. For instance, it is necessary to determine directions with an accuracy of up to fractions of an angular second, while distance must be determined with errors that do not exceed 2-3 dm.

Chronologically, the first space geodesy method -- and the one that is most widely used -- is photographic observations of AES's /artificial earth satellite/ against the background of stars. The use of the photographic method produced important results: global space geodesy networks were constructed and the harmonic coefficients of a series of models of the earth's gravitational field were determined. However, the accuracy of photographic observations is now approaching its natural limit, which is related to atmospheric turbulence, which factor prevents the determination of direction with an error of less than 0.4".

The last decade has been characterized by the extensive use of laser technology to measure distances to AES's and the laser position finding of the moon. At the present time the accuracy of laser observations of AES's is characterized by a mean-square distance error on the order of 15-30 cm. As a rule, laser stations have laser, opticomechanical and temporal subsystems.

However, distance observations, which are invariant relative to the system of coordinates, cannot give any information about it. Besides this, synchronous photographic observations in and of themselves do not insure either correlation or orientation of the observation networks relative to the general terrestrial ellipsoid or a reference ellipsoid, but do insure the preservation of the network's shape. Consequently, both methods are needed to an equal degree. An intelligent combination of synchronous photographic and laser observations contains complete information about the network's geometry, with the exception of its location relative to the earth's center of mass. Thus, while providing highly accurate determinations of the mutual location of points in the network, the geometric methods of space geodesy do not make it possible to link geodesic structures to the center of a planet's mass.

Therefore, we should regard the group of space geodesy methods known as dynamic methods as the most effective ones. In its most general form, the task of dynamic space geodesy methods consists of determining the parameters that characterize AES flight, the coordinates of observation points, and models of the forces under the influence of which an AES's flight is realized. Depending on the requirements, the methods belonging to this group can be the following:

--orbital methods, in which the models of the forces acting on an AES are assumed to be known and the coordinates of orbital points and elements are determined from the results of observations;

--methods for determining the gravitational field in which, on the contrary, the orbital elements, their temporal evolution and the coordinates of the observation points are assumed to be known, while the unknowns are the parameters of the planet's gravitational field, which are most often seen in the form of Stokes constants. In connection with this, the models of the other forces acting on an AES (atmospheric braking, solar and lunar attraction, light pressure and so on) are also assumed to be known.

In a certain sense, these two problems can be regarded as the direct and inverse problems of the dynamic method. The practical demands on space research were first directed at the development of effective methods for determining flight parameters. In connection with this, the regularity of the formulation of this type of problem is of extreme importance. In general, problems concerning the determination of a spacecraft's flight parameters from the results of measurements belong to the class of boundary-value problems. It is well known that problems of this type are extremely complex from the viewpoint of analyzing the conditions for the existence and uniqueness of a solution, as well as evaluating the accuracy of the results that are obtained.

The problem of the regularity of flight determination problems, in turn, introduces a series of conditions, among which we should first include the condition of the adequacy of the mathematical model of the flight and the model of the measurement process; that is, a requirement for their maximum closeness to the actual, existing processes.

The problem of the adequacy of models of flight is one of the most urgent problems of space geodesy at the present stage of its development. As a matter of fact, if we write the model of a ship's flight in the form of a system of differential equations in a chosen coordinate system, the right sides of these equations must contain the accelerations caused by disturbing forces, the primary ones of which are the earth's anomalous gravitational field and atmospheric resistance. Thus, adequacy of the model of a ship's flight, presumes the adequacy of the model of the plant's gravitation field, but when determining the parameters of the gravitational field's model on the basis of an analysis of the disturbances in the elements of AES orbits, we must assume that the flight model is already adequate. We thus have our own vicious circle, the only way out of which is the method of successive approximations; that is, consolidating in each of the stages either elements of the orbit or parameters of the earth's gravitational field. Consequently in the end the matter comes down to determining adequate models of the planet's gravitational field and its atmosphere and more general models of the earth that include both the harmonic coefficients and the geocentric coordinates of the stations that match them.

Meanwhile, as L.P. Pellinen has shown, satellite determinations of the geopotential are feasible for harmonics of no higher than the 16th order in the expansion of the geopotential. From this it follows that more accurate results can be obtained only by the joint utilization of terrestrial gravimetric and satellite determinations and their joint equalization.

The second necessary condition of regularity of flight determination problems is the observability condition; that is, the condition of the existence of a mutually unambiguous correspondence between the set of possible spacecraft states in the phase space and the set of measurements. Conclusions about observability or nonobservability depend to a considerable degree on the choice of the model of the spacecraft flight.

Finally, another extremely important factor is the accepted statistical criterion of the quality of the measurement processing; that is, the condition of validity of the evaluations that are obtained.

The fulfillment of all three necessary conditions for the regularity of the dynamic problems of space geodesy is frequently difficult and sometimes impossible, because of which they become incorrect. Under these conditions, the development of methods for regularizing incorrect problems in space geodesy has acquired particular importance. Therefore, it is necessary to publicize the excellent ideas and regulation methods presented in an article by Academician A.N. Tikhonov, Professor V.D. Bol'shakov and Professor Yu.M. Neyman, which ideas apply to incorrect problems in dynamic space geodesy.

Thus, when solving problems in space geodesy we should move in two directions at the saem time: to improve the adequacy of the models that are a depiction of the actual physical forms and processes, and to improve in every way possible the regularity of the problems by using the appropriate mathematical principles and ideas.

The specific nature of the construction of three-dimensional geodesic networks that encompass the territories of different continents that are separated by the surfaces of seas and the world ocean requires the development of international programs for their realization. The USSR and the socialist countries are participating actively in these types of programs and are the initiators of many of them. The "Intercosmos," "JSAGEX," "Great Chord," and "Balloon Geodesy" programs, as well as geodynamic research programs, are being successfully realized right now. The USSR Academy of Sciences' Astrosovet /Astronomical Council/ is implementing a complex of measures for the organization of an international network of ISZ observation stations and the development of modern, highly accurate equipment for these stations. Precision photographic cameras (AFU-75, VAU and SBG) and laser systems have been developed in recent years. In the "Great Chord" program, the photographic observations for determining the directions of chords have been completed, for all practical purposes, and laser observations are being made. Soviet-French stations on the islands of Kerguelen and New Amsterdam and in Kuru (French Guiana) are participating in this work. Cooperative relationships have been established with a Finnish station in Helsinki and a Swedish one in Uppsala.

The "Arctic-Antarctic" project, which links the northern and southern hemispheres with a single geodesix network, is being developed, along with an analogous "East-West" vector pattern. For this purpose, stations have been set up in Mongolia, Cuba, the Korean People's Democratic Republic, Mali, Bolivia, Equatorial Guinea, Japan, Ecuador and India. The stations of the USSR Academy of Sciences' Astrosovet have done a great deal of work in the international program and have successfully photographed synchronous AES's with the error in the directions to the AES's being only 1".

Since 1975, a program of AES observations for geodynamics purposes has been conducted in the USSR. The realization of research in this area requires the creation of integrated observatories equipped with photographic, radio engineering and laser equipment for AES observation, as well as astrometric and gravimetric instruments for enlarging the fundamental star catalogs, determining variations in latitude and lognitude, and determining the physical characteristics of tidal phenomena in the earth's body.

Projects for the laser position finding of the moon, and which are being conducted in conjunction with French scientists, were begun in the USSR in 1962. Regular laser position-finding measurements of the distances to lunar reflectors that have been made at the Crimean Observatory of the USSR Academy of Sciences' Physics Institute imeni P.N. Lebedev since 1973 show that with this method it is possible to determine the difference between the longitudes of two stations with an error of 30 cm and the distances from stations to the equatorial plane with an error on the order of 1-2 m.

Even greater opportunities for improving accuracy are available in connection with the use of radio interferometers with an ultralong base for geodesic purposes. These are all grounds for assuming that the use of ultralong-base radio interferometers for the creation of a precision time and pole movement service will make it possible to obtain information about the earth's rotation with an error of no more than $\pm 0^{s}0001$. This information does not depend on weather and therefore, is almost continuous. At the same time, the ultralong-base radio interferometer method can be used to obtain data on tides in the earth's body, the movement of continents and the longitudes of points.

The basic obstacle to the use of ultralong-base radio interferometers right now is the almost complete lack of astrometric and geodesic personnel who are capable of working with radio interferometers. Technically, the problem of using ultralong-base radio interferometers is a very complicated one. The registration of weak flows from extragalactic radio sources is done with the help of unique equipment: Amplifiers of the parametric and maser types, magnetic recorders with a band covering several megahertz, precision frequency standards with stability of about 1.10^{-13}, and antennas with a diameter of 30-60 m.

Let us spend some time on the problem of personnel training. MIIGAiK /Moscow Institute of Engineers of Geodesy, Aerial Surveying and Cartography/ is the only higher educational institution in the USSR and Europe that trains specialists in the field of space geodesy. The eighth class of such specialists was graduated from MIIGAiK in 1979. The process of formulating and organizing the new specialty was both complicated and difficult. The goal was to develop specialists with a new profile who are capable of solving modern engineering, technical and scientific problems in the field of space geodesy while preserving the latitude of geodesic education traditional for MIIGAiK. This required a thorough reworking of the classical courses in the astrometric cycle, intensification of the physical and mathematical basis of the specialty, and the introduction of extensive special courses, including a special course in celestial mechanics. It was necessary to organize academic and basic production practices in satellite astrometry, and in the organization and execution of these practices the institute received a great deal of assistance from the USSR Academy of Sciences' Astrosovet, Professor A.G. Masevich and the workers at the USSR Academy of Sciences' Zvenigorod ISZ Optical Observation Station. Through the efforts of the president's office, the institute's special departments and the methods commission, the educational process for the specialty "space geodesy" was brought into full conformity to the requirements for this specialty in a rather short period of time. Our graduates are now working successfully in many areas of the national economy, and we are receiving good reports about them.

Space geodesy, which is a creation of the last two decades, has not -- unfortunately -- avoided shortcomings caused by growing pains. This is indicated by the not always harmonious development of its methods in the areas of observation techniques and the processing of results, as well as their interpretation, where short-lived enthusiasm for some method or another is frequently experienced to the detriment of other areas for development, as well as a certain degree of amorphousness in the explication of its principles and methodology. One negative phenomenon that should also be regarded as a growing pain is terminological multiplicity, which sometimes leads to misunderstandings and sometimes to errors. As an example, we will present the same system of coordinates, which in our special technical literature has five names: 1) the fundamental system, 2) the mean equatorial system, 3) the sidereal system, 4) the stellar system, 5) the inertial system. Or yet another example from satellite astrometry: ideal coordinates, or (Terner) coordinates, or standard coordinates, or tangential coordinates. This phenomenon is explained, of course, by the rapid growth of space geodesy, but the standardization of terminology is absolutely necessary, as it has been done in other, more stabilized fields of knowledge. However, all these flaws are surmountable, and there is no doubt that space geodesy is presenting mankind with a magnificent tool for studying the world around us and is capable of revealing many unguessed secretes of nature.

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GEODESIC ASTRONOMY AT PRESENT AND IN THE NEAR FUTURE

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/Article by Professor S.S. Uralov, doctor of technical sciences, and Professor Yu.V. Plakhov, doctor of technical sciences, Moscow Institute of Engineers of Geodesy, Aerial Surveying and Cartography/

/Text/ The development of geodesic astronomy has been determined by the needs of material production that are related to the determination of the earth's shape, size and gravitational field, the construction of geodesic networks, the production of topographic surveys and the mapping of the earth's surface. This means that geodesic astronomy is one of the foundations of geodesy as a whole.

In addition to this, geodesic astronomy is a component and inherent part of modern astronomy as one of the basic fundamental sciences, the main task of which is to study the structure, physical properties and evolution of the universe, which is particularly important for a materialistic understanding of the world around us.

In continuing and developing the glorious traditions of the Pulkovo school, Soviet scientists are directing their efforts toward the further improvement in the accuracy and the methods used for astronomical determinations of latitudes, longitudes and azimuths in the middle and high latitudes.

A substantial contribution to the solution of this problem has been made by the widely known work of V.S. Zverev, N.N. Pavlov, V.P. Shcheglov, S.N. Blazhko, A.A. Izotov, V.E. Brandt, N.A. Belyayev, A.M. Starostin, A.P. Kolupayev, A.V. Butkevich, A.B. Marinbakh and V.G. L'vov, among others.

The huge contribution of Russian and Soviet astronomers and geodesists to the theory of methods of astronomical determinations is well known. The efforts of Russian and Soviet scientists have resulted in the creation of original methods that are widely used not only in our country, but in the worldwide practice of astronomical determinations. These are the widely known methods of N.Ya. Tsinger, M.V. Pevtsov, V.Ya. Struve, O. Dellen, A.K.

Shchetkin, V.V. Kavrayskiy, N.D. Pavlov, A.V. Mazayev, F.N. Krasovskiy and others.

With good cause we can be proud of the fact that a Soviet school of geodesic astronomy has been created and is being developed successfully in our country. The practical embodiment of the achievements mentioned above is the final completion of an astronomical-geodesic network in the huge area covered by the Soviet Union. However, the completion of the construction of this astronomical-geodesic network should be regarded as only the first approximation or the first stage that was absolutely necessary for the fastest possible dissemination of a unified geodesic coordinate system for all our country's territory, so that on the basis of this network it will be possible to develop complementary second-, third- and fourth-class geodesic networks.

It is a well known fact that the rigidity and accuracy of large polygonal structures is substantially less than the rigidity and accuracy of continuous geodesic networks. Besides this, the astronomical-geodesic network itself was developed over a period of many decades. During this period there were substantial changes in both the equipment and techniques used for astronomical and geodesic measurements which could not help but affect the accuracy of the astronomical-geodesic network's elements. Investigations of the accuracy of astronomical determinations of longitudes and azimuths have confirmed this conclusion.

At present and in the near future, the problem of improving the accuracy of astronomical determinations in the astronomical-geodesic network is one of the most important problems of geodesic astronomy. It is determined by the ever increasing requirements of science, technology and production for accuracy in the astronomical-geodesic foundation. At the present time, we have seen the appearance of mature, objective prerequisites for the creation of the fundamental astronomical-geodesic network in which the real accuracy of the astronomical elements would be characterized by the following values of the mean-square errors:

$$m_\varphi = 0{,}10'' \div 0{,}15'',\ m_\lambda = 0{,}007^s \sec\varphi \div 0{,}010^s \sec\varphi,\ m_{a_T} = 0{,}2'' - 0{,}3''.$$

The resolution of the problem of improving the accuracy of astronomical determinations is possible in two basic directions:
improving the methods of astronomical observations;
improving the equipment used in the observations.

It is fully obvious that in order to achieve the indicated levels of accuracy, the methods and equipment that have been used in astronomical determinations up until now are unsuitable. Many investigations have established the fact that the errors in the Laplace azimuths in the astronomical-geodesic network significantly exceed those called for in the regulations /1/. On the basis of the general theory of methods of geodesic astronomy, it has been possible to establish /2/ that the basic cause of these large errors is the accepted indirect method of determining Laplace azimuths. It has now been proven theoretically that the Laplace azimuths observed by this method in the astronomical-geodesic network that stretches from south to north over many tens of degrees were not determined with equal accuracy. For a major part of the Soviet Union's territory (approximately 70 percent of its area) to the north of $\varphi = 50^{\circ}$, the indirect methods is fundamentally incapable of providing the required accuracy in the determination of the geodesic azimuth with the observation program and equipment used for that purpose. In the northern regions, the expected random error in Laplace azimuths determined by the indirect method turns out to be double or triple what is required of them by the angular base lines of the astronomical-geodesic network.

The great flaw in the indirect method is the extremely substantial effect of the error in determining a point's astronomical longitude, as well as the systematic effect of instrument errors in determining the astronomical azimuth according to the Pole Star.

A study of the production materials of the determinations of the astronomical-geodesic network's geodesic azimuths fully confirms these theoretical propositions. A similar pattern is seen in the accuracy of the determination of the astronomical longitudes of points. The results of much research that has been done in this area indicates that there are extremely significant errors in longitudinal determinations that are both of a methodological nature and are of personal-instrumental and refraction origins. Thus, at the present time we are faced with the problem of improving the accuracy of longitudinal and azimuthal determinations, primarily in the northern regions. The solution of this problem will be based on radical improvements in both astronomical technology and observation methodology.

In recent years, the USSR Council of Ministers' Main Administration for Geodesy and Cartography has implemented radical measures for equipment development. At the present time we are completing the development of a new, precision astronomical instrument named TA-05. In the first few years of the 10th Five-Year Plan, series production of this portable, Soviet-developed instrument, which satisfies the most rigorous modern requirements, should begin.

As is well known, fundamentally new instruments for measuring time -- quartz and atomic clocks -- have been built on the basis of the achievements of modern physics and electronics. The accuracy of these instruments is greater by several orders than that of the best mechanical clocks. The frequency stability of modern quartz oscillators is 10^{-8}-10^{-9}, while that of atomic oscillators is 10^{-13}-10^{-15}. The use of the new quartz clocks and new instruments with photoelectric registration of stellar transits will make it possible not only to improve substantially the accuracy of astronomical determinations of longitudes and azimuths, but also to solve the problem of total automation of astronomical observations.

The solution of this important problem is possible, in principle, by directly linking an automated general-purpose instrument with a specialized computer.

A further improvement in the accuracy of the registration of observation times is also possible on the basis of automatic observations directly in the system of time signals transmitted by the time service's radio stations. This would eliminate the field timekeeper from the observation process.

As far as the problems of automating the office processing of the results of astronomical observations are concerned, in principle it has been solved. Small programs for computer computations for specific, particular methods have been developed in the enterprises of the USSR Council of Ministers' Main Administration of Geodesy and Cartography and are being used. On the basis of the general theory of methods of geodesic astronomy, unified computation programs for a set of methods based on the principle of measurements of the zenith distances or azimuths of stars have been developed at the Moscow Institute of Engineers of Geodesy, Aerial Surveying and Cartography and several other organizations.

In order to improve the accuracy of the determination of Laplace azimuths, the efforts of Soviet geodesists have resulted in the development of a fundamentally new technique for determining a geodesic azimuth from observations of stars at great zenith distances. Theoretically, this method should produce extremely high accuracy in the determination of a geodesic azimuth, regardless of the latitudes of the points involved. One of the possible variants of this method -- from observations of stars on the meridian -- has been recommended in the regulations /1/, although it has only been used tentatively in practice up until now. Moreover, it requires further improvement in the area of determining and allowing for the azimuthal personal-instrumental difference.

In order to determine the fundamental geodesic azimuths with the degree of accuracy indicated above, the most feasible technique is the observation of stellar transits vertically above a ground feature, using a portable instrument equipped with a photoelectric micrometer and an electronic level. The careful preliminary study of the selected directions with respect to the effect of lateral refraction has become of primary importance in the determination of fundamental azimuths. In order to weaken the effect of the topographic component of lateral refraction, azimuth observations should be made from concrete towers, at a height of at least 8-10 m above the earth's surface. For the entire profile of the direction being determined, the height of the sighting ray above any obstacles must be no less than the figure cited in the preceding sentence. In order to weaken the effect of the astronomical component of lateral refraction, which is related to the general inclination of the layers of air, it is advisable to make simultaneous determinations of the azimuths in the direct and reverse directions from observations of the same stars in the plane of the given vertical. The stars should be observed at large zenith angles (50°-80°), with an equal number of stars being observed on each side of the zenith. In order to improve the degree of accuracy and weaken the effect of refraction, the azimuths should be determined in not one, but several directions that form a simple closed figure or central system. Repeated determinations of the azimuths over several time intervals are also advisable. These are the basic features of the program for determining fundamental azimuths, the theoretical principles of which were formulated by F.N. Krasovskiy. If "...additional facilities are needed, the money should be spent" /3/ in order to implement this program.

A problem of no less importance is improving the accuracy of determinations of the astronomical coordinates of points in the fundamental astronomical-geodesic network, particularly in the high latitudes.

The problem of increasing the accuracy of astronomical latitudes, longitudes and azimuths is inseparable from the solution of a number of general astronomical problems. In particular, no matter how perfect the observation equipment and techniques are, the accuracy of astronomical determinations is limited by the accuracy of the fundamental star catalogs. Requirements for catalog accuracy need to be worked out, primarily on the basis of accuracy in determining the spatial coordinates of heavenly bodies in near space, which contemporary technology is capable of handling. For example, if the linear displacement per 10 m in the distance between the moon and the earth corresponds to an angular displacement of about 0.0005", corresponding requirements should be formulated for the star catalogs.

The accuracy of modern methods for measuring the distances and radial velocities of earth satellites now corresponds to the accuracy of the measurement of distances to artificial earth satellites (1"-2"), which (in turn) is already provided by the existing star catalogs /6,7/. However, considering the continuous progress being made with observation equipment in space geodesy, we may assume with adequate substantiation that in the near future it will be necessary to increase the accuracy of the fundamental star catalogs by a factor of at least 2-3. This will simultaneously fill the needs of geodesic astronomy. The possibility of solving this problems is determined by achievements in the development of long-base radio interferometry, which makes it possible to measure the angular distances between extragalactic point radio-frequency emission sources with extremely high accuracy (on the order of thousandths and maybe even tens of thousandths of a second). This means that a rigid "grid" of large circles yielding a practically strictly inertial system of coordinates will be realized in the celestial sphere. However, in connection with this there are two serious problems that still await solution: 1) how, without losing accuracy, to tie optical emission sources into this system; 2) how to define more precisely the position of the point of the vernal equinox. The second problem is obviously related to the problem of defining the precession and nutation constants more precisely.

The solution of these problems also depends substantially on the solution at a new and higher level of accuracy of the following problems: the investigation of the earth's rotary motion, the determination of the momentary pole's location, and the study of astronomical refraction for the purpose of allowing for its effect more accurately in the results of astronomical observations. Long-base interferometry, in combination with the methods of space geodesy, fundamental astrometry and geodesic astronomy, offers prospects for improving the accuracy of the determination of the momentary pole's coordinates. A more accurate allowance for astronomical refraction will apparently be possible both on the basis of further research in the field of atmospheric optics and by the development of observation methods that more fully eliminate the effect of refraction anomalies. It is also necessary to mention the more precise definition of the aberration constant, the proper motions of stars, and the trigonometric parallaxes of the nearest stars, which factors are related to the problems described above.

For the first time in the history of mankind, modern space technology and new space geodesy and space surveying methods make it possible to go far beyond the earth's boundaries and study all the details of the other planets in the solar system, thereby making a substantial contribution to the development of science. In connection with this, one of the important contemporary problems of geodesic astronomy is the development of methods for astronomical determinations on the surface of the Moon and Mars, our closest neighbors in space. The development of these methods has already begun and the time of their practical realization is obviously not far away. From what has been said in this article, we can draw the conclusion that in the very near future the concept of "geodesic astronomy" will consists of a broader content on a qualitatively new level. This means not only new observation equipment and methods that make it possible to determine astronomical latitudes, longitudes and azimuths with much greater accuracy than at present, but also new star catalogs, a system of fundamental constants, methods for realizing investigations of outer space and so on. Geodesic astronomy should be regarded as a whole with astrometry, theoretical astronomy, radio astronomy and other branches of modern astronomy.

On the basis of the problems described above, it is obvious that the achievements of the modern scientific and technical revolution have only begun to be used in the field of geodesic astronomy and that we, the geodesists, are still at the very beginning of this tempestuous process in our era. At the same time, however, it should be mentioned that this is a promising beginning. It is opening broad future prospects for the development of contemporary geodesic science and geodesic astronomy as one of its component parts.

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USE OF SPACE PHOTOGRAPHIC GEOLOGICAL SURVEY DATA IN PREDICTING ENDOGENIC ORE DEPOSITS

Moscow SOVETSKAYA GEOLOGIYA No 12,1979 pp 80-85

[Article by N. V. Skublova]

[Text] One of the ways of increasing reliability and efficiency of metallogenic forecasting research is the use of the set of geological-geophysical data based on mathematical methods with the application of a computer [2, 6]. In recent years, the results of decoding space photographs which contain important information [1, 3, 5, 7] are being used more and more frequently for forecasting purposes. However, the problems of quantitative evaluation of the informativeness of space photogeological data and comparison of them with the materials of the traditional geological-geophysical research has not up to now been discussed in the published literature. The purpose of the performed research was establishment of the informativeness of the space photographs for prediction and compiling metallogenic forecasting maps by space photogeological data.

Initial Data and Operating Procedure. The solution of the stated problem was realized in the example of one of the regions of the Soviet Union where a forecasting estimate was made of the prospects of finding gold by the materials of geological-geophysical work using mathematical methods and computers. The investigated territory was broken down into 1544 cells about 10×10 km^2 in size. The necessary information (with respect to 500 attributes) was gathered for all the cells, including the characteristic of the geological formations, the lithological-age complexes of the rock, the folded and broken structures of various orders, the annular structures and zones of tectonic-magmatic activation. Magnetometric and gravimetric materials were used: the values of the fields, the nature of the differentiation and orientation of the isolines. For each elementary cell the information on the presence of deposits, ore shows, signs, alluvial sands and geochemical anomalies were taken into account. As a result of processing the information by the procedure proposed by A. N. Bugayts and L. N. Dudenko [2] it was established that 50 attributes out of 500 have informativeness greater than 0.1, and the optimal results are achieved when using 25 of the most informative signs and the discriminant models. Several zones have been isolated for these data which are prospective for finding gold ore deposits, and specific recommendations are presented for the statement of the prospecting work.

We performed a structural geological analysis of the space photographs of the given territory by the previously developed procedure [4]. The space photogeological survey information including information about the regional fractures of two ranks of different orientation and annular structures and also the frequency of dislocations with a break in continuity, the degree of their latest activation and the reliability of the decipherability was encoded by the alternative binary (0, 1) attributes (see the table). The selection of these attributes is not accidental, for the preceding researchers established the leading role of the structural factor in locating the endogenic deposits. The data were recorded on magnetic tape, and they were processed at the VSEGEI Information Computer Center using the automated system of [6] also including the Prognoz [forecasting] program subsystem [2].

Sixty-four cells randomly selected among the cells where the deposits and ore shows are absent were used as the objects of the negative image. The objects of the positive image were grouped into five samples: 1 -- the gold ore deposits of quartz-sericite formation (the number of objects N = 8); 2 -- the polymetal deposits of the quartz-carbonate formation (N = 41); 3 -- the rare metal greisen deposits (N = 28); 4 -- the molybdenum deposits of vulcanogenic-plutonogenic type (N = 31); 5 -- the copper deposits of vulcanogenic-plutonogenic type (N = 32).

Informativeness of the Space Photogeological Survey Attributes. The values for the informativeness of the attributes vary within the limits from 0 to 0.458; among them both favorable and unfavorable for the location of the deposits are distinguished (see the table).

For gold ore deposits the closest relation is observed to the basic regional fractures of northwesterly and northeasterly strike. The latitudinal basic regional fractures are less informative. The meridional basic regional and secondary fractures of any directions in practice have no influence on the location of the deposits, and the presence of secondary fractures of meridional orientation is even an unfavorable sign. An obvious positive relation of the gold ore deposits to the zones of increased activation and the sections of greatest saturation with fractures is also noted.

For polymetal deposits, a strong positive relation to the basic regional fractures of northeasterly strike is characteristic. The presence of such fractures in the given case is the most informative attribute. The secondary fractures as a whole do not control the location of the polymetal deposits; The latitudinal fractures also are unfavorable for localization of them. A weak positive relation of the polymetal deposits to the annular structures and to the moderatively activated fractures is noted, and a weak negative relation, to the zones of weak activation.

For rare-metal deposits on the whole high informativeness of the space photogeological survey attributes is observed. The basic regional fractures of northeasterly strike are favorable for localization of the deposits, and the meridional fractures are unfavorable. In contrast to the other ore deposits in the investigated region, the secondary dislocations with a break in continuity are more favorable for rare metals. The association of the rare

Informativeness of space photogeological survey attributes for predicting ore deposits

Ore elements	Attributes*																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Au	+++	+++	−	+++	++	+	+	−−−	+	−	−	−	+	−	−	+++	+++	+++	−−−	−−−	−
Pb, Zn	++	−	−	+++	+	+	−	−	−	−−−	++	−−	+	+	−	+	+	++	−−	−++	−−
W, Bi	−	−	−−−	+++	+	++	−−−	−−−	+++	−−−	+++	+	+	+	−−−	++	++	+	−−−	++	−
Mo	+	+	−−	+	+	+	−−	−−−	+	−−−	+	+	++	−	−−	+	+	−−	+	−	+
Cu	−	−	−	+	−	−	−	−−−	−−−	−−−	−−−	−	+++	−	−−−	+	+	−−	+++	++	−

*1-5 -- basic regional fractures: 1 -- variously oriented, 2 -- northwesterly, 3 -- northerly, 4 -- northeasterly, 5 -- easterly, 6-10 -- secondary fractures: 6 --variously oriented, 7 -- northwesterly, 8 -- northerly, 9 -- northeasterly, 10 -- easterly, 11 -- annular fractures, 12-16 -- different saturation with fractures: 12 -- 0, 13 -- 1, 14 -- 2, 15 -- 3, 16 -- > 3; 17-19 -- intensity of latest activation; 17 -- very intensive, 18 -- intensive, 19 -- weak; 20 -- decipherability certain, 21 -- uncertain. Attributes, favorable (+, ++, +++) and unfavorable (−, −−, −−−) for localization of the deposits, have informativeness values as follows, respectively: <0.05, from 0.05 to 0.01 and >0.1.

metal deposits with the secondary fractures of northeasterly orientation is most clearly expressed, at the same time as the dislocations with a break in continuity in all other directions are unfavorable for their localization. The rare metal deposits are closely related to the annular structures, the zones of increased saturation with dislocations with a break in continuity and also with the fractures intensely activated in modern times. This regularity confirms the genetic interconditionality of these space photogeological attributes.

Quite stable negative correlations of the copper deposits to the majority of space photogeological survey attributes are noted; that is, in the given case the basic regional and secondary fractures of any orientation and the annular structures are unfavorable. The established law is confirmed by the statistical analysis data: the copper deposits are associated with the sections where the number of dislocations with a break in continuity in the cell does not exceed one, and in this case they are weakly activated in modern times. In other words, in the investigated region, in contrast to the rare metal and gold ore deposits, the copper deposits are associated with the sections distinguished by the weak latest activation of the fractures.

Summing up the data on the informativeness of the space photogeological survey attributes for predicting the leading types of minerals in the region, it is possible to draw the following conclusion: the types of deposits form an ordered series in which a regular change in degree of informativeness and favorableness in the attributes for predicting mineralization takes place from gold to copper (see the table).

The presence of the basic regional fractures is a favorable attribute for the localization of gold and polymetal deposits and unfavorable for copper deposits, that is, the degree of significance of the basic regional dislocations with a break in continuity decreases regularly in the series from top to bottom (see the table). The most favorable of all of the space photogeological survey attributes are the basic regional fractures of northeasterly strike which have not as yet received the proper amount of attention. According to the geological-geophysical data, the northeasterly dislocations with a break in continuity have ancient (Riphean) age of occurrence; they are connected with the upper structural stages and have been activated more than once. Such conclusions have been confirmed by the statistical analysis materials. The fractures are clearly reflected in the gravitational field. It must also be noted that within the boundaries of the fields outlined by the deciphered annular fractures, the northeasterly orientation of the isolines of the magnetic field predominate. Consequently, within the limits of the annular structures the activation of the northeasterly dislocations with a break in continuity was the most significant.

The meridional basic regional fractures on the whole are unfavorable for localization of the deposits, above all rare metal deposits. Among the basic regional fractures with a break in continuity of different orientation it is possible only to isolate the fractures of northwesterly and latitudinal strike with which the gold ore deposits are associated.

The secondary dislocations with a break in continuity are less informative when predicting the deposits and the basic regional fractures. However, such fractures of northeasterly strike are favorable for localization of the rare metal deposits. The deciphered latitudinal and meridional secondary fractures are unfavorable for the localization of the investigated minerals.

The role of the annular structures in the location of the deposits varies regularly from the rare metals and polymetals (favorable attribute) to copper (unfavorable attribute). This law is explained first of all by the fact that according to the statistical data for the deciphered annular structures saturation with fractures of all directions and ranks is characteristic, that is, they are associated with the intersections of the dislocations with a break in continuity. Secondly, the deciphered annular fractures are connected with the Alaskite granites of Permian age and the outcrops of Riphean series. Consequently, the majority of deciphered annular fractures coincide spatially with the Upper Paleozoic vulcanotectonic structures or the more ancient annular forms.

The deciphered annular fractures correlate most clearly with the local negative gravitational anomalies. The statistically established coordination of the annular structures with the zone of the regional gravitational minimum and also increased saturation of them with the dislocations with a break in continuity experiencing highly intense modern activation confirmed the previously drawn conclusion about the inverse relation between the intensity of the latest movements and the value of the gravitational field.

The results obtained make it possible to establish the relation between the intensity of the latest activation of the deciphered fractures and the annular structures and localization of a defined type of minerals. For the presented series (see the table) Au → (Pb, Zn) → (W, Bi) → Mo → Cu, a regular interchange of fractures favorable for the location of deposits is observed from very intensely activated to slightly activated.

The laws are less obviously established for the attributes characterizing the degree of decipherability of the fractures.

Training the Computer and Prediction. The training of the computer in the optimal version of forecasting was carried out using the discriminant model [2] with respect to 21, 18, 15, 12, 9, 6 and 3 of the most informative attributes separately for all types of minerals. With a decrease in the number of attributes the theoretical and empirical errors in pattern recognition of positive and negative images increase from 12-30% to 20-50%. For the optimal number of attributes from 18 to 21 the statistical estimate of the reliability of the production was 81% for gold, 72% polymetals, 76% rare metals, and 73% molybdenum and copper. Comparing these figures with the data of the preceding papers [2], it is possible to consider the results obtained entirely satisfactory.

Forecasting maps were constructed by computer for all types of minerals using the decision rules obtained. However, it is necessary to note that

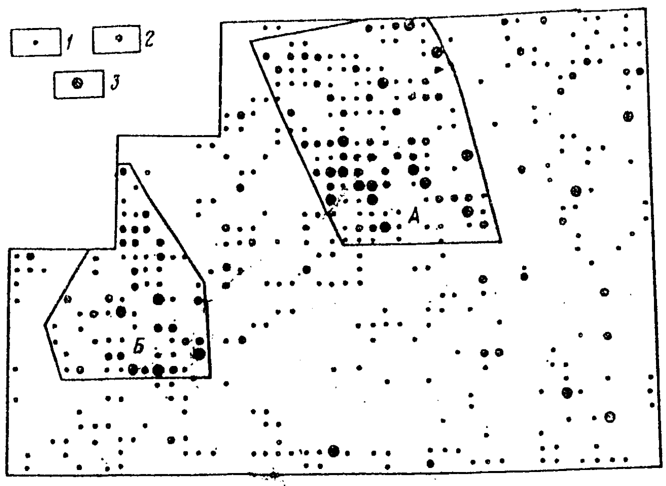

Figure 1. Diagram of the location of the prospective areas favorable for localization of the gold-ore mineralization (with respect to the space photogeological survey data). Cells: 1 -- favorable for localization of the gold ore mineralization (discriminant 2.62-4.62); 2 -- more favorable (4.62-6.62); 3 -- highly favorable (6.62 and more). A-B -- blocks recommended for searches of first and second priorities, respectively.

the degree of reliability of these maps is 72-81%, and therefore the results discussed below must be considered as preliminary. For this reason we are not investigating the isolated prospective sections in detail, but the forecasting estimate of the regional blocks is presented only in general outlines.

On the forecasting maps constructed on the basis of the space photogeological survey data, cells have been isolated which are favorable, more favorable and highly favorable for location of mineralization of various types. In the forecasting map for gold (Figure 1) the relation of the gold ore deposits to the basic regional fractures of northeasterly and northwesterly strike is clearly obvious. For finding gold ore deposits, block A 100×150 km^2 in size is of significant interest, in the southern part of which there are 6 known deposits. The territory located north of these deposits has been explored some for gold, and by the forecasting results based on the space photogeological survey data, it is deserving of primary attention. The block B is also of defined interest where signs of gold or mineralization were detected during prospecting. A series of prospective cells are traced within its limits in a zone 70 km wide and 100 km long. This block is recommended for prospecting second.

The areas prospective for finding polymetal deposits (Figure 2) have been discovered by the presence of the basic regional fractures primarily of northeasterly strike and also the annular structures and fracture zones intensely activated in modern times. The areas at the intersections of the northeasterly and northwesterly fractures appear to be highly prospective. It must be noted that the entire southern part of the investigated region appears to have low prospects for polymetals according to the space photogeological survey data.

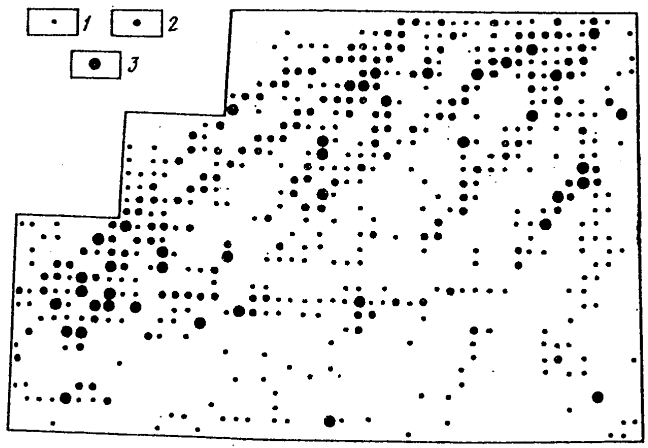

Figure 2. Diagram of the location of the prospective areas favorable for localization of polymetal mineralization (by the space photogeological survey data). Cells: 1 -- favorable for localization of the polymetal mineralization (discriminant from -216.55 to -215.55); 2 -- more favorable (from -215.55 to -214.55); 3 -- highly favorable (>214.55).

When forecasting rare metals, molybdenum and copper, a large annular structure was discovered 150 × 350 km^2 in size, in general features repeating the outlines of the regional gravitational minimum. Within the limits of this structure the following zonality is observed. Its central part is in practice oreless and nonprospective for endogenic deposits. It coincides spatially with the less eroded part of the large synclinorium, within the boundaries of which the thickness of the effusives is about 3 km. On the periphery of this zone is the successive interchange of areas prospective for rare metals, fields favorable for detecting copper and molybdenum deposits. The areas favorable for prospecting copper deposits are located beyond the boundaries of the regional gravitational minimum, as was noted earlier, in the weak activation zone. Such results again confirm the established relation between the intensity of the activation of the latest movements and the nature of the gravitational fields. On the whole, this entire annular structure has clearly expressed asymmetry with respect to prospectiveness; the northwestern part of it is more prospective for rare metals, and the southern and southeastern, for copper.

The above-investigated examples indicate that the space photogeological survey data are highly informative for predicting the endogenic deposits. The greatest effectiveness can be achieved if they are used in combination with all of the available geological-geophysical information based on the modern matematical methods of forecasting and computers.

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APPLICATION OF SPACE SURVEY MATERIALS IN MINERAL PROSPECTING

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[Article by V. A. Bush, S. P. Lebedev, G. V. Makhin, V. M. Moralev, A. V. Sadov]

[Text] For execution of the planning assignments of 1980 and the five-year plan as a whole, it is necessary to use the new technical means promoting an increase in the effectiveness of the geological operations and strengthening the mineral raw material base of the country. The space methods of geological research broadly used at the present time constitute some of the new advanced methods.

The materials of earth surveys from space contain a large quantity of information both about the geological formations widespread on the day surface (the rock composition, the peculiarities of their occurrence, the discontinuous and folded structures) and the structure of the deep layers of the earth's crust. This geological information, which to a significant degree remains unknown, permits an additional new complex of geological data to be used when predicting the mineral deposits and selecting the efficient areas of research work which will promote a significant increase in effectiveness and quality of the geological exploration work.

The space pictures for mineral prospecting are used at the present time in three basic areas. The space photographs are used for geological survey work, significantly improving the quality, completeness, detail, depth and objectivity of the geological maps serving as the base for the forecasting constructions. In addition, the space pictures permit discovery of specific structural-geological and formational criteria of the spatial arrangement of defined minerals. Here the primary role is played by the fractures of different ranks and the annular structures. The establishment of the ore-controlling factors permits localization of the exploration work and in a number of cases arriving at ore-bearing areas immediately by the deciphering results.

In both of the indicated cases the space images are used to predict minerals, that is, they are indirect methods of finding them. The third area is the application of space and aerial surveys for direct prospecting. The detection of the direct signs of the presence of minerals by remote sounding means is still in the stage of research and development.

During geological studies, including the forecasting and prospecting operations, all forms of space images are used which have been obtained by electronic, television, opto-mechanical, scanning and photographic systems.

The basic operating (in spite of all its deficiencies) method of extracting useful information from the space images of the earth's surface is their visual geological deciphering by experienced specialists. Automated machine processing of such data is in the stage of experimental investigation. In individual narrow specialized areas (for example, recognition of types of rock under defined landscape conditions) significant progress has been made.

With respect to the spatial resolution, the space images can provisionally be broken down into three groups.

1. The low-resolution photographs: on the order of 1000 meters on the terrain with a scale of less than 1:10,000,000. These are predominately television and photoscan pictures from the "Meteor" and "Meteor-Priroda" satellites.

2. The pictures of medium resolution: from 80 to 300 meters on the terrain with a scale on the order of 1:1,000,000 to 1:3,000,000. These include the photoscan pictures from certain satellites of the "Meteor-Priroda" series and photographs from the first manned spacecraft of the "Soyuz" type and the orbital stations of the "Salyut" type. The images from the American "Landsat" satellites also fall into this group.

3. High-resolution photographs: on the order of 50 meters or less on the terrain with a great variety of scales. These include, for example, the photographs taken by the MKF-6 camera from the "Soyuz-22" spacecraft and the "Salyut-6" orbital station.

The space images of various types and scales are characterized by a different degree of generalization of the geological subjects, and they are used when solving various geological problems.

The low-resolution photographs are used for tectonic regionalization and compilation of special "cosmotectonic" maps of large regions on scales of 1:10,000,000 to 1:5,000,000. Such maps already exist for the territory of Central Europe, the Eastern European and Western Siberian platforms and the northeastern part of the USSR. The interpretation of the deciphering data using the regional geophysical and geological-tectonic data permits discovery of large blocks, investigation of their articulation and processing zones, more precise definition of the internal structural plan of the blocks, mapping of the largest dislocations with a break in continuity and sutured zones and also the through dislocations with a break in continuity and the annular structures. Such maps are used for establishment of the general distribution laws of the minerals and selection of the prospecting procedure.

The photographs of medium resolution are used to compile specialized space photogeological maps of individual regions within the boundaries of the platform and folded regions on scales from 1:2,500,000 to 1:500,000. On such maps structural blocks and the zones separating them, many structural-natural complexes, regional and local geological structures, including fractures of different ranks and types, volcano-tectonic structures, free uplifts and swells, horsts andgrabens, annular structures of various dimensions and genesis, and elements of the abyssal structure of the region are distinguished.

On the basis of the indicated space photogeological survey and ordinary geological maps, a regional forecast is made of various minerals for which predominately an analysis of the structural ore-controlling factors is used. At the present time the first interesting results have already been obtained. Let us present several examples.

In the territory of Central Asia the deciphering of the space photographs of medium resolution have made it possible to isolate a number of relatively mobile zones. A comparison with the existing metallogenic diagrams of the territory demonstrated that for the mobile zones, tungsten-tin deposits are characteristic, antimony-mercury deposits are less characteristic, and for the stable blocks, the polymetal, fluorite and to a lesser degree, the copper-molybdenum deposits are characteristic. The noted law permits establishment of the metallogenic regionalization of this area and the direction of the prospecting.

A study was made of the structure of the Chatkal'skiy ridge by the medium-resolution space photographs, and several large annular fractures were isolated (see Figure 1). It was established that two of these are associated with the well-known manifestations of polymetals and copper concentrated at one of their intersections. By analogy, a second intersection of these annular fractures is assumed to be prospective.

In the Okhotsk-Chukotka volcanic belt large annular structures of predominately volcanic-plutonic genesis were discovered when deciphering the space photographs. All of the well-known ore shows of a number of nonferrous metals were taken out to the deciphering diagram, and it was discovered that they are located primarily (80%) in the peripheral part of the annular structures 25 to 50 km in diameter. Eleven such structures have been deciphered, and 8 of them turned out to be ore-bearing. The aerovisual observations and light ground operations within the boundaries of the three remaining structures also established signs of mineralization.

For the Okhotsk-Chukotka zone, an interesting experiment has been set up for joint interpretation of the deciphering data and the transformed gravitational field. The all-around analysis of the data on a computer made it possible to isolate a number of sections potentially prospective for detecting endogenic mineralization.

The analysis of a large amount of factual material indicates that many of the deposits and ore shows extend to the intersections of the annular lines

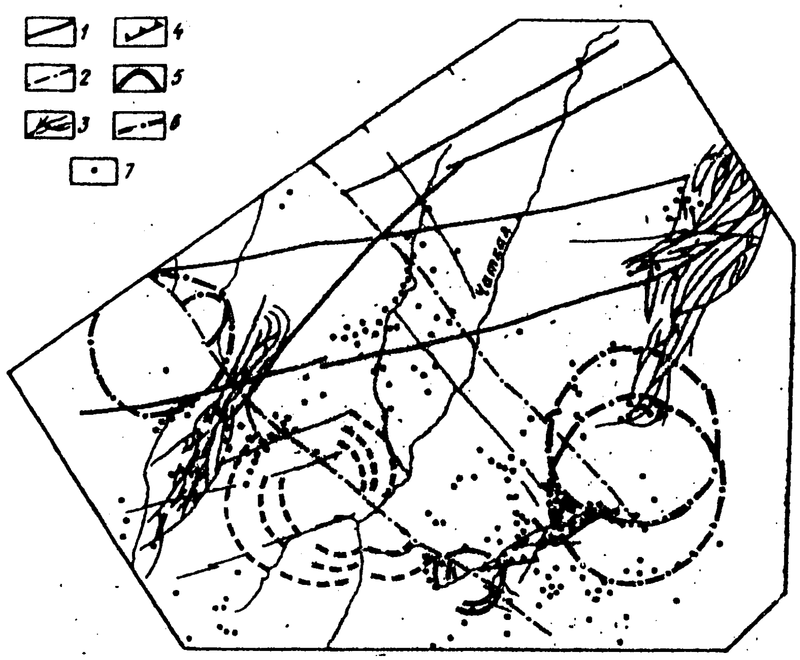

Figure 1. Deciphering diagram of the geological structures of the Chatkal'skiy ridge (compiled by Yu. L. Ivanov). 1 -- transstructural fractures of sublatitudinal (longitudinal) direction; 2 -- transstructural fractures of submeridional (transverse) direction; 3 -- other fractures and dislocations with a break in continuity, 4 -- southern boundary of the Kasansayskiy graben; annular structures traced by the jointing and increased permeability zones; 5 -- defined by concentric arrangement of small river valleys; 6 -- defined by the location and the form of the large river valleys; 7 -- ore shows of nonferrous metals.

Key: 1. Chatkal

and the transitional fractures of different direction. This type of picture is observed, for example, in Kazakhstan where the copper-porphyritic mineralization is associated with the intersections of the linear and the annular fractures.

Interesting results of deciphering the ore-bearing linear fractures by the space pictures of medium resolution (with simultaneous use of small scale aerial photographs) were obtained during the geological study of the southeastern part of the Kola Peninsula. Here a large zone of scattered dislocations with a break in continuity was discovered which previously had not been noticed, not only by medium-scale, but also by large-scale geological surveying. The extent of the zone reaches 200 km, its width in places is up to 15-20 km. When drawing the ground check routes within the boundaries of the detection zone, sulfide mineralization was detected which is traced by selective routes for tens of kilometers.

The space photographs of medium resolution are used when prospecting for oil and natural gas. Good results of predicting the potentially oil-bearing and gas-bearing structures have been obtained on the Yamal Peninsula, in the vicinity of Nizhnevartovskiy arch in Western Siberia, on the Turanskaya plate, and in the Caspian Basin. The local structures discovered by the results of joint analysis of the materials from deciphering the space photographs and seismic sounding within the boundaries of the Nizhnevartovskiy anticline are confirmed by the data from drilling operations (see Figure 2).

The only space tectonic map of its type of the Aralo-Caspian oil and gas bearing region on a 1:2,500,000 scale compiled on the basis of decoding the space photograph considering the geological research data is of unquestioned interest. The map depicts the established dislocations with a break in continuity of different ranks, the basement blocks, the anticlinal uplifts of the platform dome and the individual local structures. In addition, numerous photoanomalies are noted which are identified with the salt domes. The large-scale positive structures of the subsalt complex are of the greatest interest in the given region. A careful study of a photo of the known structures of the subsalt complex offered the possibility of using the photoanalogy method to discover the sections within which such structures were not known previously.

Geological regionalization has been carried out on the basis of the map, and prospective oil and gas bearing regions have been noted. This has made it possible to determine the primary direction and the priority of the geological operations to be performed.

High-resolution photographs, along with the aerial photographs and radar aerial photographs, are the primary materials used during geological surveying, the updating of the 1:200,000 and 1:50,000 geological maps, and local prediction and performance of prospecting work. Certain types of medium-resolution space photographs are also used as auxiliary materials for the indicated studies.

The high-resolution photographs make it possible to decipher not only ore-bearing but also the ore-surrounding structures, more completely to establish the actual composition of the geological complexes, that is, to discover the lithologic-petrographic factors in the monitoring of the equipment. At the present time there are already many examples of the efficient use of high resolution space photographs when prospecting for various minerals, including those leading to the discovery of deposits and prospective ore shows.

In one of the regions of Pribalkhash'ye it was possible to join the previously known separate manifestations of sulfide mineralization into one

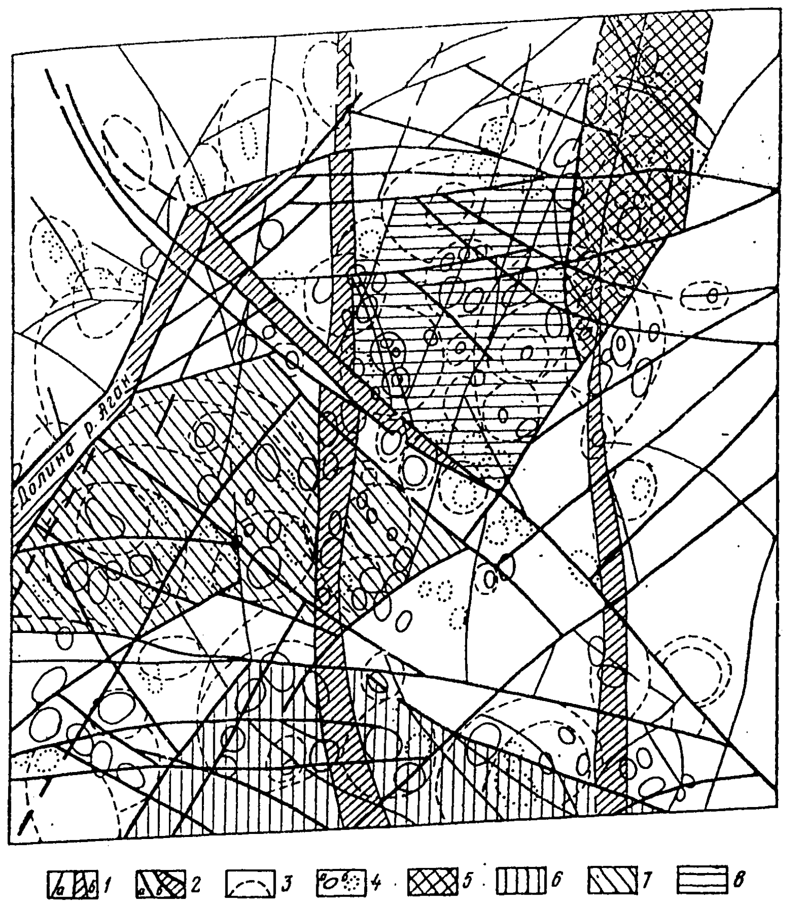

Figure 2. Diagram of the geological-structural deciphering of the region around the middle course of the Ob' River (the central part of the Western Siberian Plate). 1 -- fractures (a) and fracture zone (b) ancient (Pre-cenozoic), poorly expressed in the relief; 2 -- fractures (a) and fracture zones (b) rejuvenated in the Cenozoic time, clearly expressed in the relief; 3 -- outlines of the anticlinal uplifts deciphered by the space photograph; 4 -- dome well deciphered by space photographs (a) and less certainly deciphered (b); 5-8 -- horst blocks with different (decreasing from 5 to 8) uplift amplitude.

continuous zone by the spectrozonal high-resolution space photographs. This interpretation was confirmed by the field prospecting work and later, a number of new prospective copper ore shows were discovered here.

In the central part of the Okhotsk-Chukotka volcanic belt a large meridional fracture extending about 200 km was deciphered by the space photographs, the zone of which has two previously known ore shows of nonferrous metals associated with it. The establishment of the genetic relations of these shows to the discovered fracture has made it possible to expand the prospects of the region to nonferrous metals, to localize and more purposefully plan the prospecting work.

The complex use of the space information within the narrow zones of the spectrum and the application of computers for the recognition of combinations of spectral characteristics and the configuration of the ore fields and zones promise high prospects with respect to developing the methods of direct prospecting for minerals. The deciphering of the pseudocolor images gives many new geological data which can be seen in the example of the Turkestan and Alayskiy ridges. Here many dislocations with a break in continuity (especially transverse and diagonal to the basic folded structures), zones of increased tectonic jointing and permeability, zones of hydrothermally altered rock, and so on have been established.

In the Khaydarkanskoye ore field a number of previously unknown fractures have been deciphered, including those covered with loose deposits a few tens of meters thick. The geochemical testing of these structures has demonstrated association of antimony-mercury mineralization with them, which has made it possible to plan new areas of exploration and prospecting work. The space and high-altitude aerial photographs along with the geophysical materials have been widely used for geological study and prospecting on a scale of 1:25,000 in the Kuraminskiy rayon of Uzbekistan, where the areas for detailed prospecting work were reduced by seven times by comparison with the initial recommendations.

In addition to obtaining the geological information, the materials of the remote (including space) surveys can be used highly successfully as the base for plotting and tying in mines, test stations, geophysical observation networks and also the construction of all possible maps and diagrams.

The space methods permit us to obtain the necessary information about the conditions of formation of groundwater, the isolation of areas of its possible propagation and to give a regional forecasting estimate of the reserves. For the solution of these problems it is necessary to discover the set of natural factors (prospecting criteria) by the space photographs which directly or indirectly indicate the possibility of detecting groundwater deposits.

The indirect prospecting criteria for the groundwater deposits have been discovered most completely by the space photographic survey materials: geological-structural, lithologic, hydrogeological, geomorphological and geobotanical. The deciphering of the space photographs will permit establishment of the systems of tectonic disturbances, the fragmentation zones and the intensified jointing of the rock, the synclinal and anticlinal structures forming the artesian basins, the intermontane troughs, and so on. Rock of different lithologic composition and correspondingly with different percolation properties -- an important prospecting criterion of groundwater -- can be isolated on the space photographs. The most favorable for the formation of groundwater are the sand, sand-gravel deposits and also the weakly cemented sandstones and limestones. The hydrologic criteria characterizing the conditions that are favorable for the formation of groundwater are also established quite clearly by the space photographs. The highly informative space photographs for the discovery and estimation of the geomorphological prospecting critera of the groundwater are as follows: the debris cones, river valleys, and so on.

It is significantly more difficult to use the space survey materials to determine the direct prospecting signs of groundwater deposits. Under favorable conditions such signs can be zones of natural discharge of the groundwater in the form of large springs or sections of development of phreatic vegetation. They are recognized also by the characteristic hydrographic network or by a dark photographic tone of the space photograph.

The hydrogeological structures most prospective for prospecting fresh and slightly saline groundwater aquifers are revealed by a set of criteria on the space photographic surveys: the intermontane basins and foothill troughs, the river valleys, large artesian basins, the artesian basin of folded regions, local structures with interstitial and interstitial-karstic water.

Thus, the current experience in working with space photographs indicates that they have assumed a solid role among the other methods of studying the laws of location of minerals and prospecting for them. The application of the space photographs requires a creative approach, the consideration of the characteristic features of the investigated territories and it is inseparable from the other prospecting techniques. Geological deciphering of space photographs does not replace other techniques, but offers the possibility of using them purposefully, rejecting low-prospective areas in advance, and at the same time lowering the cost of the prediction and prospecting operations.

It is necessary to accelerate the preparation of the space photogeological survey maps of individual regions as a basis for the mineragenic prediction and specific planning of mineral prospecting. It is especially important to organize the operating testing of prospective ore-bearing zones, potentially oil and gas-bearing structures and the prosposed areas with groundwater occurrences noted from the space geological survey data.

The solution of all of these important problems will promote the implementation of the State Plan for Economic and Social Development of the USSR in 1980 and the creation of a good intermediate situation for the Eleventh Five-Year Plan in the concluding year of the Tenth Five-Year Plan.

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APPROACHES TO EVALUATING THE THEMATIC INTERPRETABILITY OF SPACE PHOTOGRAPHIC INFORMATION

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[Article by A. A. Lyutyy, A. P. Vorozheykin]

[Text] The development of methods of estimating the interpretability of space photographs as applied to the solution of certain problems of studying natural resources has important scientific and practical significance. The presence of satisfactory methods would permit more complete estimation of the quality of the space photographs and formulation of the requirements on the types and parameters of the surveys and also more purposeful processing of the survey materials.

It is obvious that the estimation of the interpretability of the space (and other) photographs is far from exhausted by the measurements and processing of the density, geometric and other characteristics of certain natural and economic phenomena which find reflection on the photographs. The interpretation process is highly complicated, in addition to the mentioned procedures it is determined by the physiological state and the intellectual goals of the interpreting specialists.

At the present time we still cannot directly measure and evaluate numerous factors determining the content of the interpreting process. Let us remember that in the practice of thematic interpretation of photographs broad use is made not only of the direct interpreting signs of certain objects, but also indirect and complex-associative signs connected with various "situational" combinations of characteristics which are determined using additional information in the form of various maps, reference materials, previously accumulated knowledge, and so on. Finally, a significant number of natural and economic phenomena can be without stable interpretable signs or be characterized by a number of similar attributes.

In practice the method of estimating the degree of interpretability of the photographs based on direct comparison of the results of field and multiple office interpretations is the most reliable. However, this method is highly labor-consuming and expensive, and therefore it cannot be realized in the near future in a volume comparable to the constantly growing volume of the performed space surveys of different types oriented toward the solution of all of the new scientific and practical problems. Therefore it is important to develop indirect methods of obtaining the estimates of interpretability of space photographs. In particular, the methods of expert estimates based on processing the corresponding conclusions of the interpreting specialists can be prospective. Inasmuch as the estimates of the degree of interpretability of the photographs will be more representative the broader the classes and higher the qualifications of the specialists involved in the analysis, it is possible to move significantly along the path of objective evaluation of the estimates of the photographic images, in other words, to make the estimates more complete, unique and noncontradictory. This can be achieved by the corresponding organization of the procedure of gathering the initial information, that is, the expert conclusions of the specialists and processing of them by statistical methods.

The studies indicate that the method of formal determination of the value of the attributes can find broad application in such problems (Nightingale, 1972). When using this method, it is quite simple to organize a broad experiment in the estimation of the interpretability of photographs considering a large number of "meaningful" characteristics (geological, geomorphological, soil-plant, economic, and so on) taken separately or in defined combinations.

Table 1. Ranks assigned by the experts

Experts	Photograph parameters				
	1	...	i	...	n
1	r_{11}	...	r_{1i}	...	r_{1n}
...	...	...	...	...	...
l	r_{l1}	...	r_{li}	...	r_{ln}
...	...	...	...	...	...
m	r_{m1}	...	r_{mi}	...	r_{mn}

The basic idea of the method consists in the fact that the attributes are assigned numerical values on the basis of the equations of the law of comparative opinions (Nightingale, 1972). The beginning phase is compiling the table of estimated ranks assigned by the experts to previously define the parameters (properties or characteristics) by their value for the solution of the defined problem (Table 1). The survey zones and types of films, the scales and also the other characteristics of them which will be assigned estimated ranks by the degree of interpretability (branch or complex) of the corresponding photographs can appear as the parameters of the photographs estimated in this way in the applications of the method of interest to us. In the complex cases it is possible to assign the estimated ranks using the methods of pair comparison and successive comparisons of parameters (Beshelev, Gurvich, 1974) which facilitate the given stage of the analysis to a defined degree.

Without discussing the calculated procedures of the method of formal determination of the value of the attributes discussed in detail in the specialized literature (Beshelev, Gurvich, 1974; Nightingale, 1972), let us consider the possible problems with respect to estimating the interpretability of the space photographs, beginning with the simple ones with subsequent complication. This permits demonstration of quite broad possibilities of the practical application of the method. Let us begin with a description of the procedures for obtaining the initial data. Let us propose that Table 1 shows the estimated ranks mentioned by the decoding specialists of the interpretability of the space photographs distinguished by certain parameters. The ranking was performed by the interpreting experts of different "thematic specialization," each of which assigned ranks with respect to importance (value) of the information recorded on the photographs to the corresponding parameters beginning with their own experience. It is obvious that in this case the summary estimates of the interpretability of the photographs distinguished by specific parameters can have a more general nature (more precisely, be thematically less specialized), since the different interpreting specialists will rank the interpretability of the photographs in the class of objects with which they most frequently deal. When using a sufficiently large number of interpreting specialists in the same or a related specialization (geologist, geomorphologist or hydrologist, and so on) it is possible to obtain more or less objective estimates of the interpretability of the photographs as applied to the corresponding branches of science and practice.

Then the summary estimates of the interpretability of the photograph obtained can be assigned a specific content, establishing the objects and their properties in advance, the readability and recognizability of which will serve as the basis for ranking the photographs by the corresponding parameters by the interpreting specialists. The lists can be limited to objects belonging to one category of natural or economic formations with one or another degree of detailing which will lead to specialized estimates of the interpretability of the survey materials. However, they can also include broad sets of objects which will lead to estimates of more or less general nature. The uniformity of their objects is especially significant for estimating the space photographs in the various zones of the electromagnetic spectrum inasmuch as the information in the defined survey channels and combinations of them turns out to be preferable for interpreting defined natural and economic objects and groups of them (Knizhnikov, Kravtsova, 1976)[1]. The use of various specialists for ranking the photographs with respect to their

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[1] In this respect the results of processing the data with respect to interpretability of the soil cover and farm crops on the materials of the multizonal aerial survey within the limits of test sections of the Kursk test area are indicative (Andronnikov, 1976). The calculated estimates completely agreed with the conclusions of the specialists regarding the advantages of one survey channel or another for deciphering various peculiarities of the soil cover and the farm crops compiled on the basis of a detailed analysis of the photographs under field and office conditions.

interpretability and expansion of the set of objects of different categories of their competence, respectively, will permit a significant increase in representativeness of the initial data.

The establishment of the specific lists of objects (branch and complex) opens still broader areas of application of the investigated estimates. It permits us to obtain comparable estimates of the interpretability of photographs at different times, for different territories with different surveying conditions and technical parameters of the camera, and so on within the limits of the same initial "volume of thematic content." Moreover, different surveying dates, different areas of investigation, and so on in themselves can be used as the evaluated parameters of the photographs.

For all of the investigated versions of the statement of the problem of estimating the interpretability of photographs, provision can be made for the possibility of extrapolation of the estimates obtained beyond the framework of the file of specifically analyzed patterns. It is insured by a defined set of photographs for analysis. On execution of it, it is expedient to be guided by the principles of experimental planning (Brodskiy, 1976). In the general case the photographs must be selected by the random sorting rules where it is necessary to select a number of like frames (in accordance with each of the analyzed parameters) from among those obtained under certain conditions. The corresponding sets of frames are presented to the interpreting specialists for ranking, and the data obtained are processed in accordance with the standard computer procedures of the method of formal definition of the value of the attributes.

When it is necessary to use spatial extrapolation of the estimates of the interpretability of the photographs (that is, propagation of the conclusions regarding the advantages of the photographs obtained in certain territories over others) to the analysis, it is necessary to use additional frames (characterized by the corresponding parameters) selected randomly by the number of territories (regions). Thus, for proper organization of the experiment it is possible to obtain the presented summary estimates of the degree of generality required in practice.

Several other schemes for stating the problems of estimating the interpretability are also possible. For example, on the basis of the previously obtained estimates of the interpretability of the previously established list of objects, ranks can be assigned to photographs that differ with respect to parameters. These primary estimates of the interpretability of certain objects can be obtained by any method, independently of the investigated method; this promotes more flexible statement of the evaluation problem. The interpreting specialists involved in the analysis of the photographs will in this case be freer to select the methods of assigning the primary estimates. Point or other forms of estimating scales can be used here.

The experimental calculations with respect to estimating the interpretability of the photographs have been performed on the basis of the analysis of the materials of multizonal space surveys obtained from the "Soyuz-22" spacecraft. In the analysis the photographs shown in three zones of the electromagnetic spectrum (yellow-green, red, infrared) with respect to three regions of the country were used. Table 2 gives a list of objects, the clearness of the recognition of which on the photographs forms the basis for expert conclusions and, consequently, the summary estimates of the interpretability of the photographs in the corresponding spectral zones produced from them[1].

Tables 3, 4, 5 and 6 show the steps in processing the data (for the entire file of objects on the list) by the algorithms of the method of formal evaluation of the attributes -- from classification of the mentioned rank estimates to checking the summary estimates of the interpretability for noncontradictoriness.[2]

Table 7 classifies the results of processing the expert conclusions both with respect to the entire file of objects and with respect to their individual thematic roots (see Table 2). They provide a basis for considering that each of the analyzed survey channels makes its own contribution to the solution of the problem of decoding the established set of objects.

The effect of the interpretability of certain objects of the initial list on the evaluations of their photographic information in the corresponding survey zones is revealed in more relief in Table 8; the relations are presented for estimates of interpretability reckoned as applied to individual "thematic" groups of objects and estimates reckoned for the entire initial file. The table data indicate the expediency of the joint use of the estimates of interpretability of the photographs by the thematic groups and space estimates when solving practical problems. The fact that no zone was obtained in any case in the analysis of the zero estimate indicates, on the one hand, the importance of using permission in each zone, and on the other hand, the necessity for more purposeful selection of the objects and groups of objects for development of their improved system of estimates.

Let us also note that the results obtained in this experiment agree with the results of other researchers, which, in turn, indicates the importance of the practical use of the proposed procedure.

Finally, let us discuss a procedural example of the solution of the problem of estimating the interpretability of the photographs which indicates the possibility of obtaining estimates for combinations of different parameters. In this example we have used black and white and spectrazonal aerial photographs on large and comparatively small scales. As the ranked parameters

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[1]The list of objects was compiled and the primary point estimate was made by I. K. Abrosimov, V. A. Bush, Ye. A. Vostokova, L. K. Zatonskiy, V. I. Somova, L. M. Tsapin, L. A. Shevchenko.

[2]The greatest divergence of the observed and calculated values equal to 0.003 turned out to be less than three times the mean linear deviation, which indicates noncontradictoriness of the interpretability estimates.

Table 2. List of interpreted objects

Thematic list of objects	Interpreted objects
Shelf shoals and coastal zone	Underwater coastal relief, circulation of water masses, underwater vegetation, "water-dryland" interface, above water part of coastal zone.
Forms of relief (geomorphological objects)	Large river valleys, small river valleys, gorges of the ravine-trough network, sinkholes, slides, abrasion scarps, surface streams, intermittent parts of rivers, large ponds, lakes, reservoirs, intermittent salt lakes, unstabilized barkhan sands, semistabilized hummocky-barkhan sands.
Soils, vegetation, farm crops	Soil type, mechanical composition, salt content of the soil, natural soil moisture, grass cover, bottom meadows, inundation glycophyic meadows, communities of phreatophytes, inundation solonchak meadows, trees and brush, windrows along roads, groves of planted trees, plowed fields, cotton, corn, alfalfa, grain crops, orchards, vineyards, boundary strips, condition of crops, sprinkler irrigation, flood irrigation.
Social and production infrastructure	Populated areas, planning of populated areas, roads -- railroads, highways, dirt roads, bridges, pipelines, hydraulic engineering structures.

Table 3. Matrix A: number of cases where the parameter i is defined as more important than the parameter j

Parameter i (survey zones)	Parameter j (survey zone)		
	Yellow-green	Red	Infrared
Yellow-green	--	9	23
Red	38	--	37.5
Infrared	24	9.5	--

we have used four combinations of "scale and film type." The list of objects of interpretation has been compiled in advance (see Table 9). The selected four photographs were presented to the group of interpreting specialists for ranking (that is, arrangement of them with respect to preference of use for interpreting specific objects). The final estimates of

Table 4. Matrix P: proportion of cases where parameter i turns out to be more important than parameter j

Parameter i	Parameter j		
	Yellow-green	Red	Infrared
Yellow-green	--	0.191	0.489
Red	0.808	--	0.798
Infrared	0.511	0.202	--

Table 5. Matrix Z: basic transformation matrix

Parameter i	Parameter j			Sum $\sum_{j}^{n} Z_{ij}$	Mean value $\bar{Z}_i$	% of the normal distribution area $G(\bar{Z})_i$	Normalized relative importance
	yellow-green	red	Infra-red				
Yellow-green	0	-0.879	-0.023	-0.902	-0.301	0.380	0.255
Red	0.879	0	0.840	1.719	0.573	0.718	0.482
Infrared	0.023	-0.840	0	-0.817	-0.272	0.392	0.263

Table 6. Checking for contradictoriness

$(\bar{Z}_i - \bar{Z}_j)$ for $i \neq j$	P_{ij} (calculated)	Deviation $\Delta_{ij} = (P_{ij} - P_{ij})$
$\bar{Z}_1 - \bar{Z}_2 = -0.874$	0.192	0.191 - 0.192 = -0.001
$\bar{Z}_1 - \bar{Z}_3 = -0.029$	0.492	0.489 - 0.492 = -0.003
$\bar{Z}_2 - \bar{Z}_3 = 0.845$	0.801	0.798 - 0.801 = -0.003
Mean linear deviation $(\Sigma\|\Delta_{ij}\|)/k$		0.0023

Table 7. Estimates of interpretability of objects

Objects of interpretation	Normalized relative importance of the parameters (survey zones)		
	Yellow-green	Red	Infrared
Entire file	0.255	0.482	0.263
Including:			
Shelf shoals and coastal zone	0.377	0.332	0.291
Geomorphological	0.266	0.440	0.294
Soil-vegetation, farm crops	0.242	0.520	0.238
Social and production infrastructure	0.056	0.673	0.271

Table 8. Ratio of the instability estimates

Objects of interpretation	Variation of the estimates by the survey parameters (zones)		
	Yellow-green	Red	Infrared
Entire file	1.00	1.00	1.00
Including:			
Shelf shoals and coastal zone	1.48	0.69	1.11
Geomorphological	1.04	0.91	1.12
Soil-vegetation, farm crops	0.95	1.08	0.91
Social and production infra-structure	0.22	1.40	1.03

Table 9. List of objects of interpretation

Thematic groups of objects	Interpretation objects
Geological	Fractures, jointing, ring structures, elements of stratification, limits of lithological differences, boundaries of intrusive rock, outlines of Quaternary deposits.
Geomorphological	Large river valleys, flood plains, river terraces, divides, small river valleys, ravine-trough network, sinkholes, erosion fault scarps : shallow sections of rivers and streams, ponds, lakes, reservoirs, thermokarstic lakes, ice.
Soil-vegetation	Mechanical composition of the soil, soil moisture, grass, trees and brush, burned-out forest.
Social and production infra-culture	Populated areas, planning of populated areas, farm sections, roads -- railroads, highways, dirt roads, electric power transmission lines.

the parameters were calculated for the entire file of objects as a whole and for individual "thematic" groups (see Table 10).

In spite of the illustrative nature of the example, the calculated estimates agree with the a priori ideas of the specialists about the suitability of the corresponding photographs for interpreting the objects of one thematic group or another; this indicates the possibility of the practical application of the given system. The objects of the economic group which are shown in Table 9 are better interpreted on large scale photographs. The objects of the geological group enumerated there are better interpreted on photographs of smaller scales. The results are higher on the spectrazonal

Table 10. Estimates of interpretability of objects

Objects of interpretation	Normalized relative importance of parameters (scale -- type of film)			
	small scale		large scale	
	black and white impression	spectrazonal impression	black and white impression	spectrazonal impression
Entire file	0.14	0.32	0.31	0.24
Including:				
Geological	0.28	0.51	0.15	0.05
Geomorphological	0.15	0.33	0.32	0.19
Soil-vegetation	0.001	0.36	0.22	0.41
Social and production infrastructure	0.001	0.01	0.49	0.49

material. When interpreting the objects of the soil and vegetation group, the difference in type of film has greater importance than the differences in the analyzed scales. When interpreting the objects of the geomorphological group preference is given to the spectrazonal photographs of smaller scale and the black and white, larger scale. Obviously, the qualitative differences of the photographs used in the analysis and the nonuniform nature of the objects of interpretation presented to the experts were felt to the highest degree.

The performed studies demonstrated the possibility of using the investigated approaches to estimate the interpretability of space survey materials. The choice of the objects, their standardization and the processing of the lists which serve as characteristic standards for estimating the survey materials used to solve certain practical and scientific problems and also for analysis of photographic images obtained under different survey conditions acquire special significance.

As applied to estimating the multizonal space information when developing standard lists of objects of interpretation and organizing the gathering of initial data it is necessary to consider the possibility of estimating the information (interpretability of the images) both in the individual survey channels and in different combinations of them.

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