

NASA TECHNICAL MEMORANDUM

NASA TM - 75041

INVESTIGATION OF NATURAL ENVIRONMENT BY SPACE MEANS.  
GEOBOTANY, GEOMORPHOLOGY, SOIL SCIENCES, AGRICULTURAL  
LANDS, LANDSCAPE STUDY

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(NASA-TM-75041) INVESTIGATION OF NATURAL ENVIRONMENT BY SPACE MEANS. GEOBOTANY, GEOMORPHOLOGY, SOIL SCIENCES, AGRICULTURAL LANDS, LANDSCAPE STUDY (National Aeronautics and Space Administration)	288 p HC A13/MF A0/G3/43	N78-11448 Unclas 49703
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Translation of "Issledovaniye prirodnoy sredy kosmicheskimi sredstvami. Geobotanika, geomorfologiya, pochvoyedeniye, sel'skokhozyaystvennyye ygod'ya, landshaftovedeniye," (Soviet report at Conference of socialist country specialists on remote sensing of the Earth with aerospace means, Moscow, Oct. 8-14, 1975), Academy of Sciences USSR, Commission of Investigation of Natural Resources with Space Means, Moscow, 1976, pp. 1-223.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
WASHINGTON, D.C. 20546

SEPTEMBER 1977



## FOREWORD

This collection, "The use of space methods to study the natural environment," contains a series of reports presented by Soviet specialists at the meeting of the section, "Methods of using aerospace information," of the Working group of Socialist countries on remote sensing of the Earth using aerospace methods (Moscow, November 17-24, 1975). /3\*

The cooperation of Socialist countries in studying the Earth's natural resources using aerospace methods is being developed in several directions connected both with the development of means and methods of remote sensing and with the anal-ysis of data, their interpretation and use in the national economy.

As is known, the first organized meeting of the Working group of Socialist countries on remote sensing of the Earth using aerospace methods was held at Baku, April 21-27, 1975. At this meeting two sections were created:

- Methods and means of studying the Earth from space,
- Methods of using aerospace information.

Materials of the meeting in Moscow, November 17-24, 1975, cover three groups of questions. The first part includes studies concerning vegetation and agricultural lands, the second -- soils and relief, and the third deals with methods.

These reports deal with methodological aspects of remote sensing of the underlying surface in different spectral intervals. Published results of studies of natural resources show that efforts to investigate the natural environment by space

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\*Numbers in the margin indicate pagination of original foreign text.

methods are being successfully developed and are gaining a wider and more varied character. Their chief importance is in demonstrating the practical value of aerospace research for the national economy, especially for efficient utilization of natural resources in agriculture. In addition, their publication has as its object the mutual exchange of information among scientists of Socialist countries on the works conducted and it will promote further joint research programs.

This collection will undoubtedly be of great interest to a wide range of specialists working in various areas of research of the natural resources of the Earth using aerospace methods.

Chairman of the Commission on the investigation of natural resources using space methods, USSR Academy of Sciences, Doctor of Technical Sciences

Yu. K. Khodarev.

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Part I

VEGETATION AND AGRICULTURAL LANDS

A. A. Alyab'yeva, D. S. Bulatov, V. V. Vinogradov, Ye. V. Glushko,  
E. D. Tamitskiy and V. S. Khrutskiy

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Study of the Composition and Condition of Vegetation of  
Pastures and Agricultural Crops  
by Aerospace Methods

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B. V. Vinogradov

Study of the composition and productivity of agricultural crops by remote aerospace methods is very important for operative collection of current information on their size, condition and potential yield. Although such information is collected through ground communication channels, it is often inadequate, inaccurate and arrives and is analyzed too late. Aerospace methods could give current information on crops in large areas synchronous in time, comparable in methods and rapid in rate of reception. Such information would permit advance production during the growing period of the regional harvest of crops, timely planning of agricultural operations and, finally, control of the performance of individual plans and projects in various agricultural provinces.

Remote sensing methods are especially important for timely detection and determination of the amount of damage to crops: floods, tornadoes, fires, droughts, diseases and attacks by insects (Frey, 1967; Luney, Dill, 1970).

No less promising is the use of remote aerospace methods for studying the productivity of pasture vegetation. The use of aerospace photos to study the development of pasture vegetation will allow timely planning of the distribution of cattle on pastures and their efficient utilization. This is especially important because the productivity of pastures varies in different years and in different seasons, depending on the weather. The average regional volume of pastures drops 3-4 times in drought years and in wet years increases the same number of times. Local deviations reach 8-10 times. Aviation modeling of this technology in Central Asia (Belyayeva, Rachkulik, Sitnikova, 1967) has already proven its effectiveness.

A complex of methods is used for aerospace studies of the productivity of crops and pastures: spectrometry in the  $\lambda\lambda$  0.4-1.3 micron range; single-band and multi-band photography in the  $\lambda\lambda$  0.4-0.9 micron range, television surveying in the  $\lambda\lambda$  0.5-0.7 micron range, thermal infrared surveying in  $\lambda\lambda$  3.4-5.6 and 8-12 micron windows, active and passive radiothermal surveying in the  $\lambda\lambda$  0.3-30 cm range and, finally, multispectral surveying in the entire  $\lambda\lambda$  0.3 micron to 30 cm range.

### 1. Spectrometric surveying of pastures and crops

Spectrometric surveying records the spectrum sweep of light reflected from the Earth's surface in the  $\lambda\lambda$  0.4-1.3 micron range from discrete areas whose frequency is sufficient for spatial characteristics of agricultural lands. The set of points on the curve of spectral brightness characterizing one area of the Earth's surface makes possible very accurate identification of the composition and quantitative characteristics of grassy and shrubby vegetation. Another aspect of spectrometric measurements of the plant cover is determination of the laws governing the formation of the signal in partial images in certain spectral intervals, as well as justification of rational selection of these intervals. /10

Let us consider the basic factors of composition, condition and development of grassy and semibrush vegetation of crops and pastures determining their reflective characteristics.

Species of plants are characterized in general by extremely uniform spectral distribution of coefficients of brightness. In the visible spectrum and in the near infrared there are two zones of absorption of light by chlorophyll: in the blue band at  $\lambda\lambda$  0.40-0.47 microns and in the red at  $\lambda\lambda$  0.59-0.68 microns, and two bands of reflection in the green zone at  $\lambda$  0.51-0.58 micron and the infrared zone at  $\lambda\lambda$  0.8-2.5 microns. However, as has been noted by almost all researchers of the brightness ratio ( $r_\lambda$ ) of vegetation (Rachkulik, 1970; Vinogradov, 1966), species differences of the  $r_\lambda$  of the plant canopy are much less important than ecology, phenology and structure.

Most clearly distinguished by spectrometric indexes are ecological types of vegetation (groups of formations) (Billings, Morris, 1951; Vinogradov, 1966) (Fig. 1).

Mesophytes, including almost all kinds of agricultural crops of meadow pastures, are characterized by typical  $r_\lambda$  with maximum brightness ratio (BR) in the green part of the spectrum  $Kr \frac{\lambda \ 0.56 \ \text{micron}}{\lambda \ 0.64 \ \text{micron}} = 1.8$ , by values of  $r_{\lambda\text{VIS}} = 0.08-0.12$  and high  $r_\lambda$  in the near infrared with  $r_{\lambda\text{NIR}} = 0.6-0.8$ . True, eury-mesophytic cereals, to which the majority of agricultural crops belong, have  $r_{\lambda\text{NIR}}$  reduced slightly to 0.5-0.6.

Xerophytic species of plants, which include a few agricultural crops and the majority of pasture species in drought zones, are distinguished by high  $r_\lambda$  in the visible part of the spectrum ( $r_{\lambda\text{VIS}} = 0.12-0.16$ ), a less pronounced maximum of  $r$  in the green part of the spectrum  $Kr \frac{\lambda \ 0.56 \ \text{micron}}{\lambda \ 0.64 \ \text{micron}} = 1.5$  and low  $r_\lambda$  in the near infrared band with  $r_{\lambda\text{NIR}} = 0.3-0.4$ .

Hygrophytic species are distinguished, on the contrary, by low  $r_\lambda$  in the visible part of the spectrum ( $r_{\lambda\text{VIS}} = 0.07-0.11$ ) and high in the near infrared ( $r_{\lambda\text{NIR}} = 0.7-0.9$ ).

The main optic factor is the phenological state of vegetation. Green growing plants have distribution of  $r_\lambda$  similar to the above with  $r_{\lambda\text{VIS}} = 0.1-0.15$  and  $r_{\lambda\text{NIR}} = 0.07-0.09$ . Dry faded plants are distinguished by high  $r_\lambda$  ( $r_{\lambda\text{G}} = 0.25$ ), especially in the red part of the spectrum with  $r_{\lambda\text{R}} = 0.3-0.4$ . Spectral contrasts of growing and dry vegetation in this range reach  $Kr_{\lambda\text{R}} = 0.6-0.7$  (Vinogradov, 1966; Rachkulik, Sitnikova, 1966). The typical seasonal curve of  $r_\lambda$  of crops in the  $\lambda \lambda \ 0.59-0.72$  micron range consists of four elements. At first there is a rapid reduction of  $r$  from 0.2 to 0.04, connected with growth development  $\lambda\text{R}$  of plants. Then the change in  $r_\lambda$  stabilizes at a low level with  $r_{\lambda\text{R}} = 0.04-0.08$ , when plants reach the budding, earing and milk ripeness stage. At the end of vegetation a rise is observed, connected with yellowing, curling up and dropping of leaves, as a result of which  $r_{\lambda\text{R}}$  is increased to 0.12-0.20 (Fig. 2). Harvesting and then plowing up harvested crops very much complicate the seasonal course of  $r_\lambda$ . Harvesting causes a further rise of  $r_{\lambda\text{R}}$  to 0.3-0.4, and plowing causes a sharp reduction of  $r_{\lambda\text{R}}$  to 0.2.

The second prevailing phytocenotic factor determining the optic properties of vegetation is its structure. A number of authors have developed and calculated a mathematical and physical model of the plant canopy, taking into account repeated scattering, transmission and absorption of radiation by the plant medium, both in

random and in oriented distribution of leaf surfaces (Allen, Gayle, Richardson, 1970; Ross, Nilson, 1968).

The main structural factor affecting the optic properties of the plant cover is the projecting canopy of green growing vegetation (P). In the visible zone of the spectrum, in particular in its red portion at  $r_{\lambda R}$ , air-dry soils (with moisture less than 2-5%) are few and moderately humus (with humus content below 4-5%). Developed in achromatic weathered soil-forming rock, they are, as a rule, brighter than vegetation (Vinogradov (1966)). This spectral contrast between soil and vegetation exceeds  $K_{\lambda}$  0.4-0.5. Among these soils are included almost all desert and semidesert soils, as well as many soils of the southern steppe and the forest zone. In the near infrared spectral band soils are, on the contrary, as a rule, darker than the vegetation of crops and pastures as  $r_{\lambda NIR}$  of vegetation varies from 0.4 to 0.8 and  $r_{\lambda NIR}$  of soils is markedly below 0.1-0.3, creating  $K_{r_{\lambda NIR}}$  (Belyayeva, Rachkulik, Sitnikova, 1966). Also vegetation is lighter in comparison with soil in the green part of the spectrum at  $r_{\lambda} = 0.49-0.58$  micron (Gates, 1965). However, contrasts in this part of the spectrum are weak ( $K_{\lambda} = 0.1-0.2$ ) and unstable. Let us consider the form of the dependence of  $r_{\lambda}(P)$ , using as an example the  $\lambda\lambda$  0.59-0.72 micron range (Fig. 3). The insignificant values of the projecting canopy ( $P < 10\%$ ) have a relatively weak effect on reducing  $r_{\lambda}$  of the plant association. The highest gradient sector of dependence  $r_{\lambda}(P)$  is found in the 10-60% coverage interval. In the 60-80% coverage interval gradients of  $r_{\lambda}$  are reduced. Here is the critical point, above which no drop in  $r_{\lambda}$  occurs with increased coverage and even a slight increase of  $r_{\lambda}$  is observed.

An important phytocenotic factor affecting optic characteristics of herbage is the height of plants. An increase in the height of plants affects change of  $r_{\lambda}$  of the plant cover equivalent to projecting canopy, but the effect is weaker. With increase of height of plants,  $r_{\lambda}$  in the most effective  $\lambda\lambda$  0.59-0.72 micron range is, as a rule, slavishly reduced (Fig. 4). The effect of height is expressed to a certain critical level, as with further increase of herbage, growth in height does not decrease  $r_{\lambda}$ . The less the projecting canopy, the greater this critical height. Thus, in mixed grass-cereal communities with 80-90% coverage the critical height is 15-20 cm (Steiner, 1961), in sagebrush-white wormwood communities with 40-50% coverage height has an effect on reduction of  $r_{\lambda}$  up to 50-60 cm (Vinogradov, 1971).

American scientists feel an important argument determining the radiation characteristics of herbage is the leaf surface index (the ratio of the area of leaf surface to the area of vertical projection - L). With increase of the leaf surface index,  $r_\lambda$  of herbage is reduced. A graph of the  $r_\lambda(L)$  ratio has the form of a second order parabola with the critical level of index L about 3-4, above which further reduction of  $r_\lambda$  with increase of index L is insignificant and can even cause an inversion (Allen, Brown, 1965; Rachkulik, Sitnikova, 1967).

All the above structural characteristics of herbage, determining its radiation properties, projecting canopy, density, height, leaf index and brightness correlate closely with the productivity of grass and shrub vegetation of pastures and crops and determine its connection with the spectral brightness ratio.

Most clearly pronounced is the relation between the phytomass (m) and spectral brightness ratios in the orange-red part of the spectrum at  $\lambda$  0.59-0.68 (0.72) micron (Belyayeva, et al., 1965; Myers, Allen, 1968). Statistical relation between SBR in this range and productivity has the form of an exponential extension function:

$$r_\lambda = am^n,$$

where a and n are parameters typical of a particular class of herbage;  $1 > n > 0$ . For example, the regression equation of  $r_\lambda(m)$  for wormwood pastures in the  $\lambda = 0.59-0.68$  (0.72) micron range is approximated in the following form:

$$r_\lambda = 0.77 m^{0.5}$$

Using an approximation of the plant community in the form of a disperse medium gives an analytical formula describing the physical essence of the  $r_\lambda(m)$  relation (Belyayeva, et al., 1966):

$$r_{sv} = \frac{r_v(r_v \cdot r - 1) + (r_v - r_s) e^{-Ema}}{(r_v r_s - 1) + r_v (r_v - r_s) e^{-Ema}}$$

where  $r_{sv} = r_\lambda$  - soil + vegetation systems,  $r_v = r_\lambda$  - vegetation,  $r_s = r_\lambda$  - soil, m - amount of above-ground plant mass per unit of area, a - constant for plant formation,  $E = \frac{1 - r_v}{r_v}$ . Standard error in determining productivity is  $\pm 0.5-1$  centners.

·hectare<sup>-1</sup>. In the infrared range of the spectrum ( $\lambda\lambda$  0.8-1.1 micron), the relation between brightness ratios and phytocenotic factors: projecting canopy, leaf index, height of herbage and productivity of vegetation, are also described by an extension function, but with the opposite sign (Thomas, et al., 1966). With increase of plant mass, spectral brightness ratios in the  $\lambda\lambda$  0.71-0.80 micron range are reduced (Belyayeva, et al., 1966b).

In the process of generalizing  $r_\lambda$  in conversion from ground measurements of individual leaves, individual plants and individual microcenoses with an area less than 10 square meters to airplane measurements of plant communities and their complexes and, finally, to satellite measurements of large areas measuring 0.5-2 km, qualitative changes occur in spectral reflecting characteristics of vegetation.

The first fact -- reduction of  $r_\lambda$  with increased scattering of the plant cover -- has long been known. Plants or groups of plants reflect 50-60% less than illuminated leaves in the visible band of the spectrum and 30% less in the near infrared band. Measurements from aircraft with little optic thickness of the atmosphere also showed a reduction of  $r_\lambda$  of vegetation communities in comparison with ground measurements of  $r_\lambda$  of individual plants. Reduction of  $r_\lambda$  of  $\lambda$  measured from low-altitude aircraft in comparison with ground  $r_\lambda$  is 10-30%.

The second factor of aerospace generalization is integration of the proportions of  $r_\lambda$  of vegetation and translucent soil in one spectrum. Reduction of the proportion of vegetation and increase of that of illuminated soil causes a flattening of the spectral contrast  $K_r \frac{\lambda 0.55}{\lambda 0.64}$ , weakening of the absorption band of chlorophyll and inner shadows of herbage, increase of the integral  $r_\lambda$  of soil-vegetation systems, especially in the orange-red part of the spectrum at  $\lambda\lambda$  0.59-0.72 micron. As a result, the course of the integral curve of  $r_\lambda$  is evened out and spectral contrasts  $K_r \frac{\lambda 0.55}{\lambda 0.64}$  are reduced from 0.5 (in ground conditions) to 0.4-0.1 (in space) (Fig. 4). The thinner vegetation is and the greater the proportion of soil, the lower  $K_r \frac{\lambda 0.64}{\lambda 0.55}$ . The effect of soil appears, beginning with a projecting canopy of vegetation under 60% (Vinogradov, 1966). In a wheat crop the green maximum  $r_\lambda$  ( $r_{\lambda G}$ ) appears only with an increase of the green mass of the wheat above 80 cent·hectare<sup>-1</sup> (Rachkulik, 1972). In the near infrared band of the spectrum the proportion of soil, on the contrary, causes a reduction of  $r_\lambda$  (Miller, Pearson, 1971).

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The third factor of generalization is the effect of the spectral transmission function of the atmosphere, as a result of which curves of  $r_\lambda$  of vegetation, measured from space from an altitude of about 200 km, are significantly deformed (Kondrat'yev, et al., 1972). The superposition of the brightness of haze, which over surfaces with more or less thick vegetation is always high, increases the  $r_\lambda$  of the plant cover in the blue part of the visible spectrum at  $\lambda = 0.40-0.51$  micron  $- 0.1-0.2$ , and in the green at  $\lambda = 0.51-0.56$  micron  $- 0.1-0.05$ . The green maximum of SBR according to spectral contrast  $K_r \frac{\lambda 0.55}{\lambda 0.49}$  is sharply reduced from 2.5, measured under ground conditions, to 1.2-1.3 (in space)(Fig. 4).

In view of the fact that direct ground calibration of elements of the space image (resolution of the multispectral scanning system [MSS] in the ERTS-1 satellite was about 0.5 ha, the TV in the Nimbus-1 AVCS satellite  $- 90$  ha, the MSS in the Meteor-18 satellite  $- 150$  ha or TV in the ESSA-8 satellite over 900 ha) is practically impossible, the following two-step method is used to determine parameters of vegetation cover. First, in test areas both on the ground and from an airplane, correlations are established between phytocenotic and remote optic characteristics similar to those given in Fig. 3. Then optic standardization of the space image is established, either by ground targets or an optic etalon. After this, integrating both these correlations and taking into account quantitative ratios of optically uniform parcels in the landscape structure, we can proceed to evaluating parameters of the vegetation by small-scale space images.

## 2. Single-band photography

For many years tests have been made to decipher on aerial photographs the distribution, composition and condition of agricultural crops and forage plants in pastures to determine their productivity. Photos were taken on panchromatic films with an orange light filter in the  $\lambda 0.57-0.69$  (0.72) micron photo-actinic zone or with a yellow light filter in the  $\lambda 0.51-0.60$  micron band. The basic signs for deciphering crops are configuration, tone and texture of the fields (Howe, 1951; Schmidt-Kraepelin, Schneider, 1966; Munn, McClellan, Phillipotts, 1966; Vinogradov, 1966; Draeger, Pettering, 1970). A very important factor in interpreting agricultural crops is the both geographic and strong seasonal variability of their photographic image (Brunnschweiler, 1957; Vinogradov, 1958, 1966; Steiner, 1961).



In the steppe zone in early spring (April), after the snow is gone and the soil dries to a softly plastic state, a field covered with stubble and last year's residue appears in a monotone, textureless dark-gray tone. In spring (May), fields freshly plowed for sowing spring crops are distinguished by a darker tone, against a background of which dissimilarities of soil formation can be noted: sinks, erosion hollows, native rock. Freshly plowed fields and spring crops are distinguished at this time from fall crops and fallow land, which appear as lighter fields of a gray textureless tone. /14

Cereal crops from shoots to the tillering phase have little effect on the gray, light-gray tone of the photographic image of the field. When staws develop (June) cereal crops develop significant growth and the image of the field becomes evenly dark-gray. During earing, cereals reach their maximum growth development and the field appears as an even dark-gray tone, masking soil dissimilarities. Blemishes, boundaries with weeds, as well as common pastures and virgin soil, beginning to dry sooner, appear lighter than crops.

Ripening and yellowing cereal crops in the wax stage of ripeness (late June-early July) sharply increase reflective capacity in the visible band of the spectrum and appear as light gray, lightish-gray tones. At this time maximum tone differentiation of agricultural crops is observed, depending on the rate of ripening: early ripening crops of oats, winter rye and wheat appear lighter than late-ripening spring wheat and corn. Harvested fields (July-August) appear as a monotone gray, light-gray tone, blending with the tone of virgin soil. Freshly plowed autumn cropland and fallow areas (August) again give a dark tone to the image of fields.

The distribution, configuration, composition and condition of crops have repeatedly been recognized in black-and-white and color space photographs. On the color photograph of Texas, made in the spring from Apollo-6 in 1968, fields of winter wheat are easily distinguished in a dark green color (Shay, 1969). On color photographs of the Imperial Valley in California, taken from Gemini-5 in September, 1965, it was possible to recognize all fields larger than 16 hectares, primarily barley with tonal variations depending on density and condition of the crops (Collwell, et al., 1970). On black-and-white space photographs from the manned spacecraft Soyuz-9 and the manned orbiting station Salyut-1 fields of various agricultural use are differentiated with varying reliability (Fig. 6).

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As an example, let us consider the photograph of the Sal'sk steppe taken from Soyuz-9 on June 15, 1970, from an altitude of 228.4 km on panchromatic film with a light-yellow light filter in original scale at the subsatellite point of about 1.7560000. During the photography, the height of the Sun was 21° (Vinogradov, Sevast'yanov, Serdyukova, 1973, 1974).

The studied section is located in the Sal'sk-Manych watershed in a subzone of the dry steppes. The locality is a gently rolling plain with weakly cut gullies and valleys of small rivers. Soils in the watershed are chestnut, saltish, in large part (50-70%) plowed and used for agricultural crops. Virgin vegetation is represented by well-worn wormwood and saltbush, now and then feather-grass dry steppe.

Agricultural lands and the condition of cereal crops in the field were selectively described simultaneously with photographs from Soyuz-9 in June, 1970, and then more completely in the entire area of the key section — by farm maps of the location of agricultural crops in 1970 — all fields in the V. I. Lenin Collective Farm, the "Zavety Il'icha" Collective Farm in the Zimov region; the "Pervomayskiy" State sheep farm and the "Privetinskiy" State sheep farm in the Remontniy region of Rostov oblast.

Crops occupy 60% of the area. In crop rotation cereal crops predominate: spring barley and winter wheat. Small amounts of rye, oats, millet, corn, Sudan grass, annual and perennial grasses are grown. In the middle of June the milk-wax and wax ripness stage of cereal crops begins and harvesting on June 25. However, from the end of May all annual grasses and some cereals (barley, rye) are cut for green forage. Early mown winter crops as well as those destroyed by frost or wind are plowed under and reseeded with barley, which matures much later than early sown barley. Pastures on slopes and bottoms of gullies and ravines, as well as cattle trails also occupy 38% of the section, 2% of the territory is occupied by separate farms and gardens and reservoirs.

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Used to identify the location, composition and condition of agricultural crops were prints of space photographs, magnified 38 times, and special subsatellite aerial photographs made in the same year near the time of the space photographs in a scale of about 1:70 thousand. Results of field observations and data from farm maps of the location of crops for 1970 were first identified on aerial photographs taken in 1970 and then, using the aerial photos — on space photographs from Soyuz-9.

Enlarged space photographs are used to differentiate the following elements of the agricultural landscape: fields with agricultural crops in various stages, pastures, cattle trails, villages and separate farms, reservoirs, river valleys with meadow-swamp-brush vegetation and gardens (Fig. 7).

The first step in photo interpretation is separation of plowed areas from unplowed. With reliability approaching 100% fields are recognized by the darker tone and rectangular structure of the photographic image. The structure of fields is rectangular with a 1:1, 1:2 and 1:4 ratio of the sides and strict meridional latitudinal orientation of the boundary network. It is noted that as dryness of the climate increases from west to east, the amount of soil plowed is correspondingly reduced, in the "Zavety Il'icha" collective farm - 70%, in the "V. I. Lenin" collective farm - 64%, in the "Pervomayskiy" state sheep farm - 54%, in the "Privolenskiy" state sheep farm - 53% and in the "Rodina" collective farm in the transitional area to semidesert - only 33%. Judging by field interpretation of space photographs and the recognition of these fields on farm land use maps of collective farms and state farms, on the photographs against a background of virgin soil it is possible to recognize all fields whose measurements vary from 16 to 400 hectares, i.e., fields with sides over 400 m. Field boundaries are shown more accurately on photographs than on land use maps and, therefore, they can be updated by space photographs. Certain fields are shown on maps in different places than on photos and in field observations. Finally, there are fields recorded on photographs which are omitted on land use maps. Therefore, they can be inserted into maps according to the space photographs. Along the perimeter of fields boundary corrections in some land tenures amount to 5%.

Within the field area in a practice key section it was possible to identify fields with crops of winter wheat, spring barley, winter rye, oats, corn, Sudan grass, millet, mustard, perennial and annual grasses, as well as fallow areas overgrown with annual and biennial weeds, cleared fields with stubble and freshly plowed fields. The basic sign of interpretation is the tonal density of the image. Because the resolution of low-contrast details in space photographs was 250 m, the interior texture of fields was not seen. The tone of the image was determined, on one hand, by the growing mass of crops, and on the other by the phenological stage of development. These two characteristics under conditions of uniform ground cover, identical climate and similar agrotechnology correlate with the composition and condition of agricultural crops. However, these same factors determine tonal varia-

tions of the image of the same crops even in the same region.

For each of the above mentioned agricultural crops and lands graphs were plotted of the frequency distribution of visual valuations of tone densities on the positive image. A total of 475 agricultural contours were analyzed. There is a marked difference between different collective farms which is, evidently, connected with differences in agrotechnology on individual farms. Let us consider tonal characteristics of cultures described according to representative samples. The probability of reliable (with error less than 0.1) discrimination of individual crops in general is high and varies from 0.6 to 0.9. Nevertheless, there are examples of correcting collective farm maps of the distribution of crops in fields using the tone signatures of space photographs.

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In the darkest tone appear thick, tall (to 70-100 cm) and late maturing crops of corn and Sudan grass. Fields of thick Sudan grass appear primarily dark-gray, corn is a darkish-gray tone. Lightening of the tone of some contours is connected with early cutting of crops for green forage. Also appearing in a predominantly dark-gray tone are fields of oats which, as a rule, are reseeded later in lost crops of winter wheat and, therefore, mature late.

The main cultures of the region - winter wheat and spring barley - appear in the earing and milk-wax ripeness stages primarily in a darkish-gray tone with great dispersion of tone.

Perennial and annual grasses show a wide range of tone on the image from dark-gray to light-gray due to their early cutting and the variety of grass agrotechnology.

Ripe crops and stubble after grain harvest have the highest brightness ratio among ground objects, reaching  $r_{\lambda} = 0.25-0.30$ . They occupy a very small area and appear on the picture in a lightish-gray tone.

Fallow areas occupied by annual and biennial mixed grasses appear primarily as a darkish-gray tone but show great dispersion of tones from lightish-gray to dark-gray, as last year's and new fallows are considered together.

Freshly plowed chestnut soils have the lowest brightness ratios ( $r_{\lambda}$  in the photoactinic range = 0.08-0.14) and their brightness is comparable to that of a

cloud shadow. Their image tone on the picture is dark. As they dry, chestnut soils increase  $r_{\lambda}$  to 0.12-0.18 and the tone changes to dark-gray.

Common pastures with trampled down wormwood-saltbush pastures appear as an even lightish-gray tone. Their areas are located along gullies and ravines and are easily distinguished by tone (lighter) and shape (not square) from the primarily darkish-gray areas of fields. Gray winding bands of gullies are visible against a background of pastures. In places dark-gray bands of tree and brush vegetation, melon fields and kitchen gardens are noted in the gullies. Cattle trails are recognized distinctly by the light-gray right-of-way with exceptionally down-trodden vegetation, running from east to west for a distance of over 50 km. Besides the light-gray tone of the cattle trail itself, there is a distinct gray veil of dust in the atmosphere and in adjacent fields. Field-protecting forest belts are 10-25 m wide and are not recognized on photographs, but they significantly increase the clarity of boundaries between fields.

The classification of pasture vegetation by its productivity is based on identification of the texture and tone of the photographic image and geographic interpretation of the environment (Vinogradov, Kudryavtsev, 1964; Falkner, 1961; Vinogradov, 1970). Based on the above considered relations between spectral reflective and structural characteristics of pasture vegetation (Fig. 3), it can be concluded that the density of the positive image in filming on panchromatic film with an orange light filter, i.e. in the  $\lambda = 0.57-0.69$  (0.72) micron photoactinic zone, should increase in proportion to the increased thickness and coverage of green growing vegetation (Vinogradov, 1958, 1970, 1971). And, in fact, against a relatively light background of soil, the following ratio is observed between the projecting canopy and the tone of the positive image of pasture vegetation: light tone - coverage < 10%, light-gray - 10-30%, lightish-gray - (30) 40-50%, gray - 50-60%, darkish-gray - 70-80% and dark - 80-90% (100%). Densitometric measurements of panchromatic aerial photographs showed a close relation between the density of the negative image (D) and the phytomass of semidesert tree and shrub vegetation (m). The equation of dependence D(m) is described by a curve in the shape of a parabola (Fig. 8). Maximum values of  $D = 1.5-2$  correspond to the image of soil deprived of vegetation or with productivity less than 1 centner·hectare<sup>-1</sup>. Minimum values of density  $D = 0.3-0.4$  are observed for critical productivity, above which no reduction of density is observed with increase of plant mass. Such a critical ordinate falls at 10-20 centner·hectare<sup>-1</sup> of dry mass (Vinogradov, 1961). The correlation of dependence D(m) is

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quite high, making it possible to measure productivity by the density of the negative with standard error of 0.5-1 centner·hectare<sup>-1</sup>. However, selection of values must be strictly districted in the locality and limited to one phenological season.

### 3. Multiband photography

Single-band photography on one-layer black-and-white film, even photography on multilayer color and spectrozonal film do not, however, provide the necessary recognition reliability for the composition and conditions of crops and pastures. Only a comparison of optic densities of the image in different spectral bands can give reliable information (Vinogradov, Kondrat'yev, 1961). Space experiments were preceded by numerous aviation tests of multiband photography of crops on color spectrozonal infrared film with blue, green and red light filters and with no light filter (Steen Von, Leamer, Gerbermann, 1969) and synchronous filming of crops with multiobjective (4-9) cameras using various films with various light filters (Colwell, et al., 1960)(Fig. 9).

Space multiband photographs were taken March 8-12, 1969, by Apollo-9 from an altitude of 190-240 km. The photos were taken with a four-objective camera with  $f = 80$  mm and various film + light filter combinations:

Film:	Photoactinic zone:
A. Color infrared	0.51-0.89 micron
B. Panchromatic	0.47-0.61 micron (effect of atmospheric diffusion)
C. Black-and-white infrared	0.68-0.89 micron (overexposed)
D. Panchromatic	0.59-0.71 micron

The photographs had an original scale of 1:2.4 - 1:3,000,000 with the resolution element about 100 m.

Studies were made of multiband images of crops in the Imperial Valley, south of the Salton Sea in Southern California (Fig. 10) (Anuta, MacDonald, 1971), (Wiegand, Leamer, Wever, Gerbermann, 1971), (Nalepka, 1970), (Colwell, 1972). All studies were based on comparison of interpretations of multiband space photographs or synchronous altitude multiband aerial photographs (from about 21 thousand m) in bands imitating multiband space photography with ordinary (from altitudes of 1500 and 3000 m) aerial photography on analogous types of film and ground studies of the com-

position and condition of agricultural crops in key sections of the Imperial Valley in March, 1969.

The Imperial Valley is a flat inter-mountain plain with primarily irrigated farming. The climate is subtropical semidesert. Soils are dark brown. The Valley is almost completely taken up with crops of barley, alfalfa, sugar beets, rice and onions. In addition, at the time of photography, i.e. in March, part of the arable land is occupied by long-fallow land and plowed soils seeded with cotton. There are also saline areas unsuitable for farming.

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Criteria for photo interpretation of crops were worked out in key sections where individual fields were identified in space photographs. These sections were used to train the photo interpreter. Then, synchronous altitude and ordinary aerial photography in comparable spectral intervals was used to extrapolate and recognize crops on space photographs of the entire region. Two kinds of errors are taken into consideration in extrapolation. "Omissions" occur when a field in the studied class is erroneously assigned to a class with a different crop composition. Such errors are determined by the ratio of incorrectly identified fields to the total number of fields in a given class ( $T_c/T$ ). "Commissions" occur when fields of a class with a different crop composition are erroneously assigned to the studied class. Such errors are determined by the ratio of correctly recognized fields to the total number of fields in a given class ( $T_c/\bar{T}$ ). Finally, the index of correctly identified fields to the total number of fields assigned to a given class was determined ( $T_c/T$ ). Different groups of specialists have shown different interpretations of fields in the Imperial Valley on multiband photographs from Apollo-9 and multiband aerial photographs compared with them. However, in level of errors the results are, in general, similar to each other.

The highest accuracy of recognition is obtained in color infrared photography from Apollo-9 (Zone A). In color infrared photographs fields registered from pink to dark red. Onion fields are pale pink to green, fields of sugar beets from dark red to red, rice fields also from dark red to red with a noticeable and thick irrigation system, soils without thick vegetation are gray and green shades.

The following conclusions were reached as the result of analysis by an experienced photo interpreter. The resulting accuracies ( $T_c/T$ ) with which agricultural crops can be identified in multiband space photographs vary from 70 to 80%

(while the required accuracy is 90-95%)(Table 1)(Colwell, 1972).

Table 1

ACCURACIES OF RECOGNITION (in %) OF AGRICULTURAL CROPS IN A KEY SECTION OF THE IMPERIAL VALLEY BY MULTIBAND PHOTOGRAPHY FROM APOLLO-9 (Colwell, 1972)

		Zone A	Zone B	Zone C	Zone D	Maximum minimum
Barley	$T_c/T$	73	83	63	87	87
	$T_c/\bar{T}$	6	43	16	48	6
Alfalfa	$T_c/T$	21	21	74	9	74
	$T_c/\bar{T}$	13	11	67	23	11
Soil not covered with vegetation	$T_c/T$	64	82	56	45	82
	$T_c/\bar{T}$	1	6	0	2	0

In comparison with altitude multiband aerial photography (Table 2), it is noted that the accuracies in Tables 1 and 2 are of the same order.

Photointerpretation of the composition of crops by images obtained in multiband aerial photography from lower altitudes over the same key section in comparable scales to the multiband photographs from Apollo-9 preserves the order of accuracy (Table 3).

Table 2 19

ACCURACIES OF RECOGNITION (in %) OF AGRICULTURAL CROPS IN A KEY SECTION OF THE IMPERIAL VALLEY BY MULTIBAND AERIAL PHOTOGRAPHY (Colwell, 1972)

		Zone A	Zone B	Zone C	Zone D	Maximum minimum
Barley	$T_c/T$	40	63	60	53	63
	$T_c/\bar{T}$	18	40	50	21	18
Alfalfa	$T_c/T$	68	94	32	47	94
	$T_c/\bar{T}$	47	84	22	34	22
Soil not covered with vegetation	$T_c/T$	64	81	55	68	81
	$T_c/\bar{T}$	0	33	10	3	0

Lower accuracies of identification of alfalfa are connected (as in the above example of perennial grasses in the Sal'sk key section) with differences in agro-technology (crops ripe, unripe, recently cut). Barley crops with the most stable herbage gave the highest accuracies of recognition among agricultural crops.



Table 3

ACCURACIES OF RECOGNITION (in %) OF AGRICULTURAL CROPS  
IN A KEY SECTION OF THE IMPERIAL VALLEY ACCORDING TO  
MULTIBAND AERIAL PHOTOGRAPHY FROM 1500-3000 M

	$T_c/T$	$T_c/\bar{T}$
Barley	78-61	20-11
Alfalfa	4	0-3
Sugar beets	89-78	3-8
Rice	88	20-24
Plowed soil	100	5-9
Salt marsh	100	0
Onions	40-20	0

The main problem in the recognition of agricultural crops on space photographs is the speed of analysis and operative output of information giving advance notice of crop development. Therefore, solution of the problem is closely connected with quantitative methods of recognizing crops on space photographs.

For basic agricultural crops in fields (sample  $> 10$ , minimum size of field 30 acres or 350 x 350 m), average optic densities of the positive image were obtained in all possible film + filter combinations and standard errors (dispersion) of density were calculated from this average. As shown by comparison of average density values, taking deviation into account, the average values are not reliable signs for distinguishing crops. Therefore, differences were calculated in average values between three black-and-white images (3 differences) and between three filtered and one integral reading of a spectrozonal image (6 differences). Then, the dispersion interval was superposed on differences of average values. Lack of superposition of density dispersions indicates that areas are distinguished with a probability of 0.95.

Besides densitometric characteristics of partial images, of great importance in the analysis of multiband photographs is comparison of geometric characteristics such as amplitude and periods of fluctuations of optic density and their frequency-spatial analysis (Vinogradov, 1966). As an example of such analysis, let us present several results of synchronous multiband aerial photography made in 1961 by the Laboratory of Aerial Methods of the USSR Academy of Sciences using various films with photoactive intervals in the orange-red spectral band at  $\lambda$  0.58-0.69 micron with maximum  $\lambda$  of sensitization 0.63-0.65 micron (on panchrome-10 film), in the

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green-yellow spectral band  $\lambda$  0.52-0.62 micron with maximum  $\lambda$  0.58-0.59 micron (on panchrome-10 film), in the green-yellow spectral band  $\lambda$  0.52-0.62 micron with maximum  $\lambda$  0.58-0.59 micron (on RF-3 film) and others (panchrome-15, 17, Panifra). Strict sensitometric control was provided by correct comparison of multiband photographs both by photometric and by geometric characteristics. Test areas were located in different landscape combinations of forest-steppe zone vegetation: water meadows with a medium level of mesophytic-mixed grass-couch grass-sedge low-lying swamps, osier beds growing on alluvium, fields with shoots of agricultural crops. Densitometry of negatives with a relative aperture MF 0.035 mm gave comparable registrograms, made of identical points of the locality (Fig. 11). Statistical analysis of registrograms led to a number of correct conclusions about the selection of optimum spectral intervals for photography and evaluation of the deciphering criteria for different landscape combinations of vegetation. For example, analysis of registrograms of multiband photographs showed that the deciphering informational value of frequency-spatial characteristics of amplitudes and optic density is much higher than average periods of fluctuations of different orders, amplitudes and density. Filming in the green-yellow part of the spectrum  $\lambda$  0.52-0.62 micron gives best results in early-season tree-brush and partly meadow mesophytic vegetation. In the orange-red part of the spectrum  $\lambda$  0.59-0.69 micron, pictures of fields, thin vegetation and swamps are distinguished by the best indexes.

Individual negatives of multiband photography of the Imperial Valley were scanned by a microdensitometer and the optic density of the negative was expressed in digital form (Wiegand, 1971; Anuta, MacDonald, 1971). The aperture of the microphotometer in the first experiment was 0.25 mm, it provided resolution of 60 m and was slightly less than the resolution of the film (100 m); in the second it was 0.6 micron, i.e. slightly larger than the first - 180 m. Besides the three black-and-white images (zones B, C and D), the spectrozonal image (zone A) was sequentially scanned with blue, green, red and no light filters. Thus, seven partial images in digital form were recorded on magnetic tape in a volume of 35 million readings.

There were two modifications of digital multiband classification for each point of measurement and for a set of points by fields (30 x 30 points), as well as by combinations of zones A, B, C and D and by combinations of zones B, C and D (Table 4). Agricultural crops, like soil and hydrological factors, were automatically identified by digital notation of the image. Accuracy of distinction is very high in plowed soil, salt marshes and reservoirs, but recognition of individual agri-

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cultural crops, as a rule, does not reach the necessary level of accuracy (90-95%).

The training complex of the test section was about 7 km square and presented 5906 elements of resolution. The area of extrapolation occupied 350 sq km and was comprised of 93,900 densitometric elements. Classification by subsets (30 x 30 points), including all points in the field, in general gave higher accuracy of photo interpretation than classification by points, with the exception of crops varying greatly in agrotechnology, such as alfalfa. Low values of classification by points were in some cases assumed to be due to an insufficient test set (sugar beets, salt marshes) and in others - to nonuniformity of the texture of the contour (salt marshes). However, classification by fields demands division of the set of

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Table 4

COMPARISON OF ACCURACY OF RECOGNITION (in %) OF AGRICULTURAL CROPS IN A KEY SECTION IN THE IMPERIAL VALLEY IN FOUR MODIFICATIONS: "BY POINTS" AND "BY FIELDS", BY CHANNELS A; B; C AND BY CHANNELS B; C, D IN MULTIBAND IMAGES FROM APOLLO-9

	By fields	By points	By fields	By points	Maximum
Barley	8.6-67.7	72.7-70.8	75.0-71.0	71.2-76.6	78.6
Sugar beets					
Alfalfa	68.2-54.5	43.6-27.8	59.1-72.7	48.5-26.6	68.2
Arable lands	9.1-42.1	36.0-41.7	27.3-42.1	38.2-39.2	42.1
Salt marshes	82.4-95.7	77.6-86.3	82.4-91.3	77.2-85.8	95.7
Water	100.0	59.0-4.8	100.0	70.5-9.5	100.0
Average	100.0	97.2	100.0	72	100.0
	70.8-68.2	60.0-61.1	69.7-70.6	62.0-62.1	70.8

points into subsets (i.e. fields) of points, which either complicates automation of photo interpretation or leaves the process semiautomatic with contours of fields outlined manually.

The poor accuracy of recognition of agricultural crops on multiband photographs from Apollo-9, which was expected, can be explained by its imperfection. Poor recognition is determined primarily by the lack of sensitometric control of photo data of multiband photography from Apollo-9. Lack of calibration made it impossible to correctly determine optic characteristics of individual crops. There are also other ways of improving the technology of multiband photography of agricultural crops. First is selection of the optimum season, multiseasonal photography and comparison of different-season photos. For example, May pictures give higher accuracy of recognition of barley and alfalfa in the Imperial Valley (83-90%) than

March when crops are not sufficiently developed in growth (Colwell, 1972). A palliative way of increasing the accuracy of photo interpretation is combination of agricultural crops into biological groups, for example, small grain winter cereals, the same for spring, large grain cereals, legumes, root crops, perennials, annuals, fodder grasses, etc. Spatial resolution of photographs is not only not a limiting factor, but judging by data collected "by fields" and "by points," high resolution photography (at least 250-300 m) can be used for multiband technology. Finally, a large reserve of multiband photography is the finer specification of spectral zones for classification of fields such as, for example, 0.54-0.56, 0.64-0.68, 0.78-0.82 microns.

#### 4. Thermal infrared surveying

The spatial and temporal structure of thermal radiation of crops and pasture vegetation is very complex. It varies not only depending on composition and condition of vegetation, but also on illumination and weather conditions. Therefore, it is difficult to give general signs for the interpretation of images of vegetation obtained in windows at  $\lambda = 3.4-5.5$  microns and 8-12 microns. Data obtained on the interpretation of vegetation by infrared aerial photographs, although limited, show the possibilities of interpreting infrared images.

Radiation temperatures of a plant community (part of the vegetation + soil system) ( $T_{rad}$  °C) are determined primarily by the temperature of the leaf surface of plants. This, in turn, depends on the water content of plant tissues (Gates, Tantraporn, 1952; Olson, 1967; Myers, et al., 1970). Ground and laboratory radiation measurements have shown that in warm summer weather with air temperatures over 10-15°C and bright sunlight, when a strain of the water balance can be observed, green growing plants, as a rule, are cooler than dry plants and the soil surface. It has been indicated that the temperature of leaves of mesophytic plants due to transpiration is reduced an average of 1-5°C. Plants with a stable water supply have a leaf tissue temperature 1-5°C lower than those with an inadequate supply.

With a reduction of water pressure the gradient of reduction of leaf temperature is 1°C per 10% turgor (Fig. 12). Temperature differences between plants exposed to the Sun and shaded reach 10-12°C. In the above indicated weather conditions it is possible to trace more or less clearly the inverse relation between

thermal and water conditions of the plant.

However, hydrothermal characteristics of plants are subject to strong diurnal, weather and seasonal variations.

Maximum temperature contrasts of plants, depending on their water supply during the summer in the steppe zone, come in the afternoon hours of 2-4 p.m. when there is the greatest strain of the water balance. Low contrasts are observed in the evening at 9-10 p.m. and in the morning at 8-9 a.m. and, finally, the minimum in the pre-dawn hours at 5-6 a.m. Thus, the daily course of temperature contrasts of vegetation is more inertional than contrasts in the soil surface where maximum contrasts occur in the prenoon hours at 10-12 a.m. local time. Night photos of vegetation in the infrared spectral band are not very promising, as at night temperature contrasts of vegetation, connected with differences in water conditions and vitality are reduced 10-20 times in comparison with the daytime.

Wind reduces temperature differences of plants with different water content and at a wind speed over  $10-15 \text{ msec}^{-1}$ , overheating of insufficiently transpiring plants is practically unnoticeable. The effect of wind strongly affects the thermal infrared image of fields of agricultural crops. It not only reduces contrasts, but also superimposes extended bands of wind flow of various speed on the image of fields.

Cloudiness and rain also reduce temperature differences. However, thermal infrared aerial photographs in clear, dry and warm weather in daytime hours clearly differentiate agricultural crops, depending on the stage of their growth.

Soils and dry plants at this time are significantly warmer than growing plants. The illuminated surface of the soil can be heated  $10-30^{\circ}\text{C}$  higher than communities where the soil is almost completely covered with herbage.

Thermal infrared aerial photographs of crops have been taken in windows at  $\lambda$  3.4-5.6, 3.0-4.1, 4.5-5.5 and 8-14 microns (Olson, 1967; Myers, et al., 1970; Vinogradov, Grigor'yev, Lipatov, Chernenko, 1972). Images in the far infrared zone of the spectrum at  $\lambda$  8-14 microns are undoubtedly of great interest in comparison with the  $\lambda$  3.4-5.5 micron zone where the effect of reflected sunlight is still significant.

In daytime thermal infrared aerial photographs (Fig. 13) the brightest (warmest) are old fields with a compacted and air-dried surface. Crops of oats in the wax ripeness stage with yellowing leaves are depicted by slightly darker light-gray tone. Against a background of plowed fields and crops a gray tone indicates wet soil and light bands - drainage lines. Green growing crops of clover and wheat give dark-gray, dark (cold) tone, against a background of which brighter spots indicate blemishes, disturbed and trampled crops.

Existing space survey systems in the thermal infrared range from the Meteor satellite at  $\lambda$  8-12 microns and NOAA and Nimbus at  $\lambda$  10.5-12.5 microns have too great spatial resolution: the first 25 km and the second 7.2 km. However, since 1975 the Landsat natural resources satellite has been providing pictures obtained by a scanning radiometer in the  $\lambda$  10.5-12.5 micron range with a spatial resolution of 200 m. Such images can be used for observing the condition of crops, primarily water conditions of vegetation. An increase of radiation temperatures in this spectral band can signal an inadequate moisture content and difficulties in transpiration of vegetation long before visible signs of wilting appear.

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## 5. Multispectral surveying

The most effective means of observing the composition, condition and productivity of crops and pastures is synchronous multichannel surveying in narrow spectral bands - to 0.02 micron and with a wide range from ultraviolet at  $\lambda$  0.28-0.30 to infrared at  $\lambda$  8-14 microns. Such narrow specialization of bands, on one hand, reduces the input of excess information and provides comparison of signals of the same object in different channels and, on the other hand, increases the reliability of recognition to the required level of probability - 0.90-0.95. Difficulties arising in analyzing numerous multispectral images are connected with poor understanding of spatial-temporal variability of spectral reflective characteristics and the complexity of their quantification and automation of analysis.

The efforts to develop multispectral scanning systems (MSS) for studying natural resources made by the Laboratories of the University of Michigan and Purdue University have given positive results (Polcyn, Spansail, Malila, 1969; Holter, 1970). 12 and 18 channel MSS developed in the United States include 12-13 channels in the visible and near infrared spectral bands and 5 in the thermal infrared. At the

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Table 5

1. 0.32-0.38 micron	1. 0.40-0.44 micron
2. 0.40-0.44 micron	2. 0.44-0.46 micron
3. 0.44-0.46 micron	3. 0.46-0.48 micron
4. 0.46-0.48 micron	4. 0.48-0.50 micron
5. 0.48-0.50 micron	5. 0.50-0.52 micron
6. 0.50-0.52 micron	6. 0.52-0.55 micron
7. 0.52-0.55 micron	7. 0.55-0.58 micron
8. 0.52-0.58 micron	8. 0.58-0.62 micron
9. 0.58-0.62 micron	9. 0.62-0.66 micron
10. 0.62-0.66 micron	10. 0.66-0.72 micron
11. 0.66-0.72 micron	11. 0.72-0.80 micron
12. 0.72-0.80 micron	12. 0.80-1.00 micron
13. 0.80-1.00 micron	
and in infrared:	
14. 1.5-1.8 micron	
15. 2.0-2.6 microns	
16. 3.0-4.1 microns	
17. 4.5-5.5 microns	
18. 8.0-13.5 microns	

present time specifications are established for 24 and 30 channel MSS (Zaitzeff, 1971). Such equipment has for the first time provided researchers with complete utilization of remote methods for studying agricultural crops and ecological problems..

Beginning in 1966, several tests have been conducted in the United States using MSS for studying agricultural lands. Local results in each individual experiment were extremely significant. /24

A multispectral survey of agricultural crops was made on May 5, 1966, at 2 p.m. from an altitude of 1000 m near the Wabash River immediately southwest of Lafayette (Holter, 1970). In a valley with brown-forest highly leached soil it was possible to distinguish (Fig. 14) crops of winter wheat in the tillering stage (1), shoots of oats (2), red clover (3), freshly plowed fields (4), freshly plowed and seeded fields with air-dry soil surfaces (5), last year's fallows (6) and other kinds of agricultural lands - pastures (6), unfavorable areas (7), forests (8) and farms (9).

The relative contrast between crops of oats and freshly plowed fields is noticeable on the image in the  $\lambda$  0.66-0.72 micron spectral range, but disappears in the  $\lambda$  0.62-0.66 micron range and arising again in the  $\lambda$  0.58-0.62 micron range, it merges slightly in the shortwave range. Crops of wheat and red clover and freshly plowed fields in the  $\lambda$  0.66-0.72 micron range show no marked contrast, in the

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$\lambda$  0.62-0.66 micron range a freshly plowed field is lighter than green crops. In the  $\lambda$  0.55-0.58 and 0.52-0.55 micron ranges crops have a similar image, although wheat is slightly darker. In other shortwave ranges plowed fields are also lighter than crops. In the visible range of the spectrum, fallows and plowed and seeded fields are lighter than freshly plowed soils, increasing especially in the  $\lambda$  0.44-0.48 micron range.

Relative contrasts in the near infrared band of the spectrum at  $\lambda$  0.72-0.8 and 0.8-1.0 micron differ completely from those that occur in the longer wave range. In these spectral ranges significant contrasts are noted between freshly plowed fields (darker) and fallows or plowed and seeded (lighter) fields; these disappear in the far infrared band of the spectrum. Wheat and other green crops appear light in spectral ranges of the near infrared range at  $\lambda$  0.72-0.80 and 0.8-1.0 micron and dark in all the rest. Thin crops of young oats in the near infrared range at  $\lambda$  0.72-0.80 and  $\lambda$  0.8-1.0 micron, are darker, and in the visible band of the spectrum, especially at  $\lambda$  0.50-0.52, 0.52-0.55 and 0.55-0.58 micron ranges are lighter than tall winter wheat and give a tone transitional between close crops and reflected soil.

A survey of agricultural lands using an 18 channel MSS was made near Camp Davis, California, on May 26, 1966, at 4 p.m. from an altitude of 600 m (Polcyn, Spansail, Malila, 1966). In the complex conditions of varied agrotechnology of irrigated farming the authors separated individual components of the agricultural ecosystem. Plowed soil, gravel embankments and dirt roads were isolated by images in the  $\lambda$  0.48-0.50 and 0.58-0.62 micron ranges. Rice fields were recognized, primarily, by images in the  $\lambda$  0.72-0.80 micron range of the near infrared spectral band which, however, was disturbed by differences in soil moisture and the projecting canopy of vegetation. Safflower crops were distinguished by images in the  $\lambda$  0.48-0.50 and 0.62-0.66 micron ranges.

In the state of Indiana on May 6 and June 30, 1966, surveys were made of agricultural crops from altitudes of about 1000 and 3000 m using a 10 channel MSS in the  $\lambda$  0.4-1 micron range. According to data of the June survey, accurate recognition of wheat fields by the 10 channel MSS survey ( $T_c/T$ ) was 70.8% from 3,000 m and 82.8% from 1000 m, and erroneous determinations ( $T_c/\bar{T}$ ) 0.29% and 0.08%, respectively (Cowell, 1972).



Extensive studies of agricultural lands were conducted in the state of Indiana in the Lafayette area by the Laboratory for Agricultural Remote Sensing at Purdue University. The survey was made with a 12 channel MSS on June 28-30, July 26-28 and September 15, 1966, in the "Corn Belt" on brown-earth soil. It was possible to recognize crops of corn (C), soybeans (S), red clover (R), alfalfa (A), wheat (W), oats (O) and rye (Y), bare soil (X) and surface water (I).

Analysis of the results obtained by 12 channel MSS in the Lafayette area of Indiana on July 28, 1966, showed accuracies of recognition of agricultural crops from 52.4% for alfalfa to 78% for wheat (LARS, 1968, Table 6).

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Table 6

ACCURACIES OF RECOGNITION OF AGRICULTURAL CROPS WITH 12 CHANNEL MSS  
 $\lambda$  0.4-1.0 MICRON RANGE OF PURDUE UNIVERSITY (LARS, 1968)

Agricultural lands	Exact determination (Tc/T in %)	Erroneous determination (Tc/T)
Bare soil	100	0.1
Wheat	78	0.1
Soybeans	76.7	4.6
Oats	73.9	3.1
Rice	73.0	1.7
Corn	65.5	7.7
Clover	69.6	4.7
Alfalfa	52.4	1.6

The training sample was determined visually on "uniform areas without large patches of weeds, thin spots or bare soil." Such correct recognition (Tc/T) of large grains (corn + soybeans) was 91.5%, small grains (wheat + oats + rice) - 87.1% and perennial grass (alfalfa + clover) - 77%. With expansion of the subsets to such integral entities as green vegetation, bare soil and water, accuracies reach levels of 99.4, 98.0 and 96.7% (Hoffer, Johannesen, 1968).

A MSS survey experiment was carried out in the Imperial Valley synchronously with the flight of Apollo-9 on March 12, 1969, between 10.06 and 10.31 a.m. local time in 10 channels in the  $\lambda$  0.4-1.00 micron range (Nalepka, 1970). The purpose of the study was multispectral simulation of multiband space photography from Apollo-9, substantiation and comparison of multiband photography and a multispectral survey. On color spectrozonal films, the yellow color-forming layer is sensitive to the reflection of green vegetation ( $\lambda$  0.53-0.58 micron) and completely summarizes two channels of the MSS - 7 and 8 (see above Table 5). The red color-forming layer is

sensitive in the light absorption range to chlorophyll ( $\lambda$  0.62-0.68 micron) and corresponds to MSS channels 10 and 11, although peaks of sensitivity of the photographic images and MSS channels do not coincide. Finally, the infrared color-forming layer, sensitive to the increased reflective capacity of green vegetation in this part of the spectrum ( $\lambda$  0.7-0.9 micron) corresponds to MSS channels 12 and 13, which are less sensitive in the  $\lambda$  0.75-0.85 micron range, but compensate this sensitivity in the  $\lambda$  0.85-1.0 micron range.

According to an international biological program on the Central Plains biome in the state of Colorado (USA) in September, 1968, a survey was conducted with a 6 channel MSS in the  $\lambda$  0.4-1.0 micron range (Wagner, Colwell, 1971). Differentiated by various intensities of the spectral image were five categories of agricultural lands with different productivity of dry plant mass: (1) soil without vegetation or with thin vegetation and a plant mass reserve of 0-30  $\text{g}\cdot\text{m}^{-2}$ , (2) low-grass communities of buffalo grass  $> 35 \text{ g}\cdot\text{m}^{-2}$ , (3) short-grass prairies of grama grass  $> 65 \text{ g}\cdot\text{m}^{-2}$ , (4) medium grass prairies of feather grass and wormwood  $> 110 \text{ g}\cdot\text{m}^{-2}$  and tall grass prairies of couch grass 200 or more  $\text{g}\cdot\text{m}^{-2}$ .

A number of authors have given specific recommendations for using a particular narrow band of the spectrum to recognize the composition, thickness and phase of development of crops and type of agricultural lands (Nalepka, 1970; Holter, 1970; Colwell, 1972). Measurements made in several minutes in flight, however, require many months of analysis and development of an automatic system of identification. In addition, the geographic and seasonal variability of the image of crops determined the set of algorithms for crops at different times and in different regions. Then it was found that the accuracies principally achieved - 0.8-0.9 - are not adequate for their practical utilization. Finally, it was shown that minimization of the number of channels to 3-4 is not accompanied by a reduction of accuracy. The productivity of agricultural ecosystems is determined in stages and includes: (1) subdivision of biotic and abiotic components of ecosystems, (2) revealing spatial and temporal variations of individual components of ecosystems.

In this MSS (Holter, 1970) it was first possible to carry out successful remote surveying in the near ultraviolet band of the spectrum  $\lambda$  about 0.3 micron. Interesting data were obtained concerning recognition of agricultural crops: distinguishing ripe cereals such as wheat (which can have low spectral reflectivity and, therefore, a dark tone on the image) from light-gray thin crops, bare soil and cereals

disturbed and damaged by diseases. In the  $\lambda$  0.32-0.38 micron range, MSS distinguished orchards with rodent damaged-trees by a lighter tone, which was due to a disturbance of the formation of green leaf tissue (Polcyn, Spansail, Malina, 1969).

Space operation of the multispectral scanning system began July 23, 1972, when multispectral images were obtained from the first natural resources satellite ERTS-1. A four-channel MSS camera with the following parameters was mounted in ERTS-1 (Table 7):

Table 7

CHARACTERISTICS OF MULTISPECTRAL SCANNING SYSTEM AND THE ERTS-1 SATELLITE

channel 4 :  $\lambda = 0.5-0.6$  micron  
channel 5 :  $\lambda = 0.6-0.7$  micron  
channel 6 :  $\lambda = 0.7-0.8$  micron  
channel 7 :  $\lambda = 0.8-1.1$  micron

SPATIAL RESOLUTION OF DETAILS OF MAXIMUM CONTRAST: 70 m

scanning width - 185 km  
longitudinal overlap along equator - 14%  
periodicity of coverage - 18 days  
output original scale - 1:3.2 million  
output scale - 1:1 million  
scale of image presentation - 1:250 thousand  
Declination of orbit -  $99^{\circ}$   
period of rotation - 103.3 million  
ground speed -  $6.45 \text{ km} \cdot \text{sec}^{-1}$   
progression of orbit -  $25^{\circ}.8$  longitude  
height of orbit - 920 km

In the Sacramento River Valley of California, recorded on the transformed image, from ERTS on July 25, 1972, at 10 a.m. local time (Figure 14), two kinds of conclusions can be made comparing the images. One category of objects appears much better on one of the spectral images. The second category of objects is determined by comparing synchronous spectral images.

For example, to the first category, where objects are easy to see on one of the partial images and poorly visible or even not represented at all on others, belong rivers. Butte Creek, Phizer Fork and even such a large river as the Sacramento

are hard to trace on partial images in the  $\lambda$  0.5-0.7 micron range and then, chiefly by indirect signs: field boundaries and relief. On the contrary, in partial images in the  $\lambda$  0.7-1.1 micron range they can all be traced by the dark more meandering lines of waterways.

However, the most important is, of course, comparative decoding of multi-spectral images.

At the end of July in late summer, fields are very physiognomic, but at the same time give a very variegated image, depending on the stage of ripening of the crops, harvest of crops and plowing of fields.

In the  $\lambda$  0.5-0.6 micron range fields with thick and green growing crops appear darkest. A slightly lighter tone distinguishes thin and ripening crops and plowed fields.

In the  $\lambda$  0.6-0.7 micron range fields with green crops, as well as reservoirs and wet irrigated fields with thin vegetation or none appear dark. A gray, light-gray tone distinguishes fields of ripening and yellowing agricultural crops, harvested fields and plowed fields with air-dry soil. A light tone distinguishes fields of ripe, dry agricultural crops.

In the  $\lambda$  0.8-1.1 micron infrared range a dark tone distinguishes primarily reservoirs, wet and moist soil, as well as freshly plowed fields. Fields of ripe dry and yellowing or harvested crops appear gray. Finally, fields of green and thick crops in the growing stage have the lightest tone.

Thus, from the above description it is evident that groups of agricultural lands cannot be distinguished in one partial image. However, by means of comparing multispectral images they can be distinguished quite confidently. Reservoirs, wet and moist soils have a dark tone on channels 6 and 7 and dark-gray or even darkish gray on channels 4 and 5. Green agricultural crops, like moist soil, appearing dark or darkish-gray on channels 4 and 5, differ sharply from their light or lightish-gray tone on channels 6 and 7. Plowed air-dry soils are distinguished from green vegetation by a lighter, light-gray tone, in particular on channel 4, and on the contrary, by a darker gray tone on channel 7. Ripe and harvested dry agricultural crops are poorly distinguished from air-dry soil by a gray, lightish-gray tone on channel 7, but well distinguished from them and from green crops by a lighter, light

or lightish-gray tone on channels 4 and 5.

## 5. Radiothermal sounding

Space systems for measuring radiothermal radiation of the Earth from Kosmos 243, 384 and other satellites in the  $\lambda$  0.8, 3.5 and 8.5 cm ranges still give too great spatial and temperature resolution (30-50 km and 1-3°K) to obtain necessary information on the condition of agricultural crops. Active radar systems for measuring radiothermal reflection in the  $\lambda$  1-100 cm ranges are generally not installed in satellites in view of their great energy expenditures. Nevertheless, they have a number of advantages which are forcing intensive development of methods of radiothermal sounding in satellites and their modeling in aircraft, especially their sensitivity to the geometry of the plant cover and their invariability in relation to cloudiness and time of day. Surveys are being conducted or are being planned in bands:

Ka at  $\lambda$  0.8 cm  
K at  $\lambda$  1.13-1.67 cm  
X at  $\lambda$  2.42-3.66 cm  
S at  $\lambda$  7.6-11.53 cm  
L at  $\lambda$  17.65-25.8 cm

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Surveys of agricultural lands in the states of Kansas and California, USA, in the Ka range at  $\lambda$  0.3-1.0 cm showed close correlation of the reflected signal with parameters of crops measured in the field (Fig. 15). The basic factors controlling the reflected signal were geometric parameters of the crops: projecting canopy and height of herbage. Survey tests in the Ka range in the state of Indiana, USA, showed the promise of using radar in combination with surveys in other spectral bands. In autumn measurements, high radiation was given by corn or soybeans, medium values by alfalfa, pastures and stubble and very low signals by plowed soils and water surfaces. In tests distinguishing fields of sugar beets and corn in the Ka range, probabilities of correct classification ( $T_c/T$ ) were 97% and 92%, and the probability of erroneous classification ( $T_c/\bar{T}$ ) 0.2% and 0.5%, respectively. Thus, the potential possibilities of surveying in the radiothermal range reach the required level of probability, i.e. 0.95-0.99.

A significant improvement in radiothermal surveying was made by measuring vertical and horizontal polarization of the reflected signal in the Ka range, as well

as by comparing the Ka-signal obtained at different times (Haralick, Caspall, Simonett, 1970; Holter, 1970). Further expansion of radiothermal surveying to 4-5 frequency ranges, including zones K, X, S, L and P in the  $\lambda$  1-100 cm range, in combination with three kinds of polarization, will ensure a universal effect of the system, the main advantage of which is independence of time of day, illumination, condition of the atmosphere and cloudiness.

## CONCLUSION

Aerospace surveying of agricultural lands is extremely effective, but at the same time complex and requires a great volume of methodological work and expenditures for its realization. Recommendations for development of such surveying in the next stage of development of space systems for surveying agricultural lands might include the following.

Selection of spectral bands. Three universal bands are recommended for surveying agricultural lands:

- $\lambda$  0.52-0.58 micron,
- $\lambda$  0.62-0.72 micron and
- $\lambda$  0.8-1.0 micron.

Also, additional ranges are recommended for solving particular problems in observing the condition of agricultural crops, measuring parameters of ecosystems, excluding the effect of atmospheric-astronomic conditions and increasing the reliability of interpreting composition:

- 0.30-0.32 micron,
- 10.5-12.5 micron and
- 0.8 cm.

Scale and spatial resolution. Mapping land use structure and identifying crops with probabilities of 0.95-0.99 require aerospace remote systems with spatial resolution of 10-50 m, which is a relative scale of 1:100 - 1:500 thousand. For synoptic surveying of the development of crops and the agrotechnological condition of fields a resolution of 200-250 m is sufficient (i.e. relative scale of 1:2 - 1:2.5 million), and for observation of the development of pasture vegetation - 800-1000 m (i.e. a relative scale of 1:8 - 1:10 million).

Periodicity of survey. For surveying the condition of agricultural crops the most efficient periodicity is surveying once every one or two weeks during the growing season. During this time it is possible to detect phenological deviations in the development of agricultural crops from average data of many years, unfavorable growth conditions connected with droughts, dust storms, wilting, development of diseases, spread of herbivorous insects and extreme changes in soil moisture.

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## DESIGNATIONS

- $\lambda$  - wavelength of electromagnetic oscillations
- $\lambda\lambda$  - spectral interval
- $r$  - brightness ratio
- $r_\lambda$  - spectral brightness ratio
- $r_{\lambda, \text{VIS}}$  -  $r_\lambda$  in the  $\lambda\lambda$  0.4-0.7 micron interval
- $r_{\lambda, \text{NIR}}$  -  $r_\lambda$  in the  $\lambda\lambda$  0.7-0.9 (1.1) micron interval
- $K_r$  - optic contrast =  $\frac{r_1 - r_2}{r_1}$
- $K_{r\lambda_1/\lambda_2}$  - zonal optic contrast of two spectral intervals
- $r_{\lambda R}$  -  $r$  in the  $\lambda\lambda$  0.6-0.7 micron interval
- $D$  - optic density of photographic negative
- $f$  - focal distance of photographic objective
- $m_d$  - phytomass of vegetation, dry weight
- $m_w$  - phytomass of vegetation, wet weight
- $T_{\text{rad}}$  - radiation temperature
- $T$  - kinetic temperature
- $T$  - radiobrightness temperature
- $P$  - projecting canopy
- $L$  - leaf index

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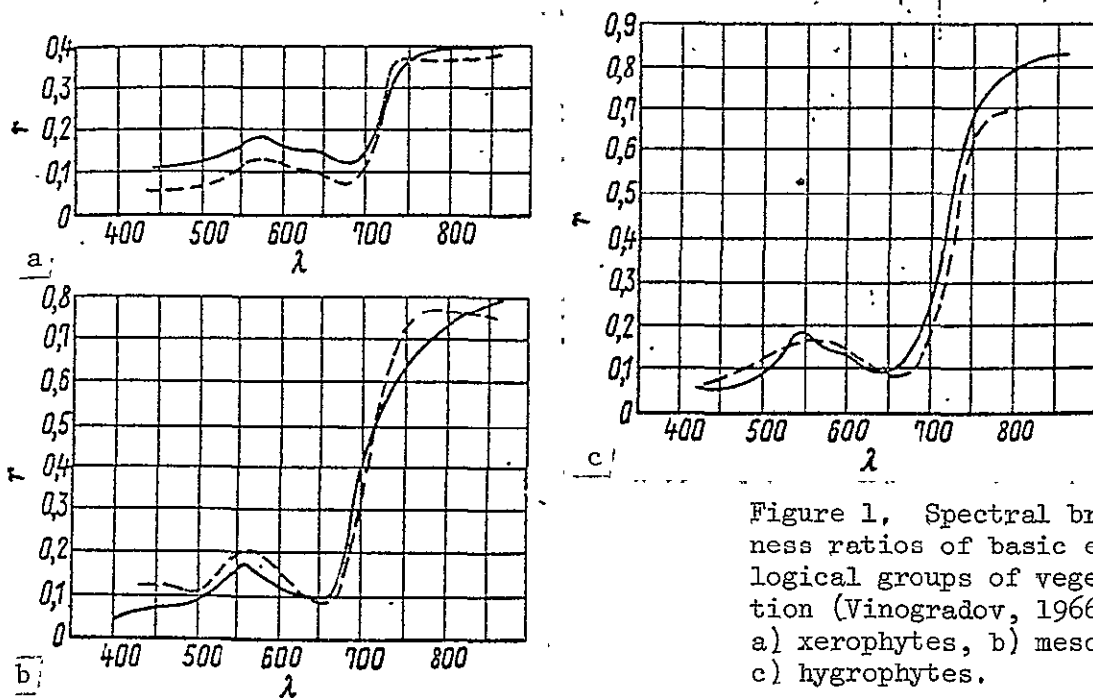


Figure 1. Spectral brightness ratios of basic ecological groups of vegetation (Vinogradov, 1966): a) xerophytes, b) mesophytes, c) hygrophytes.

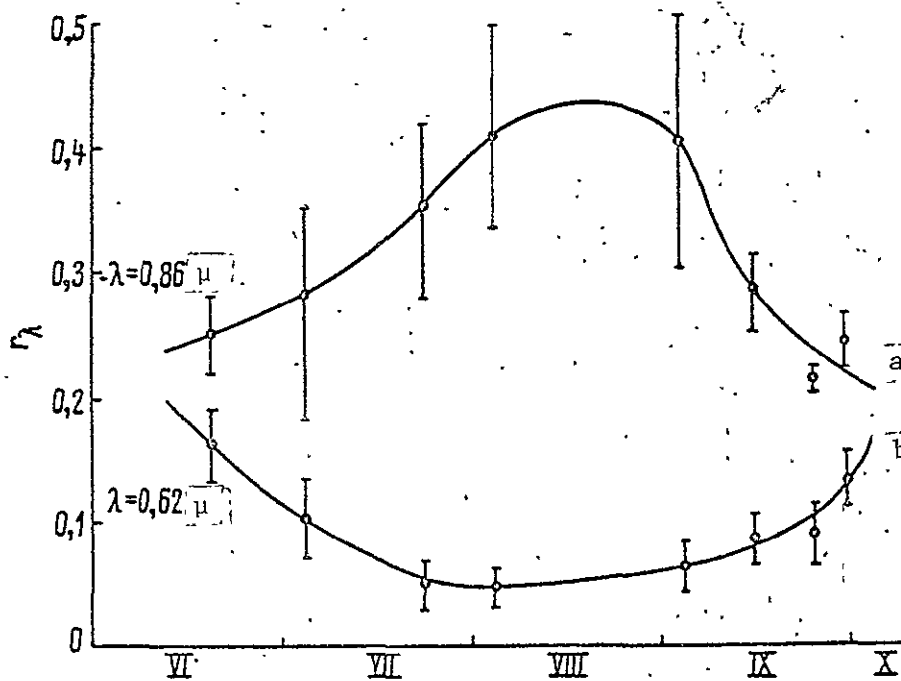


Figure 2. Seasonal course of spectral brightness ratios of cotton (Belyayeva, Rachkulik, Sitnikova, 1967): a - in  $\lambda$  0.59-0.72 micron spectral interval and b) in  $\lambda$  0.68-1.20 micron.

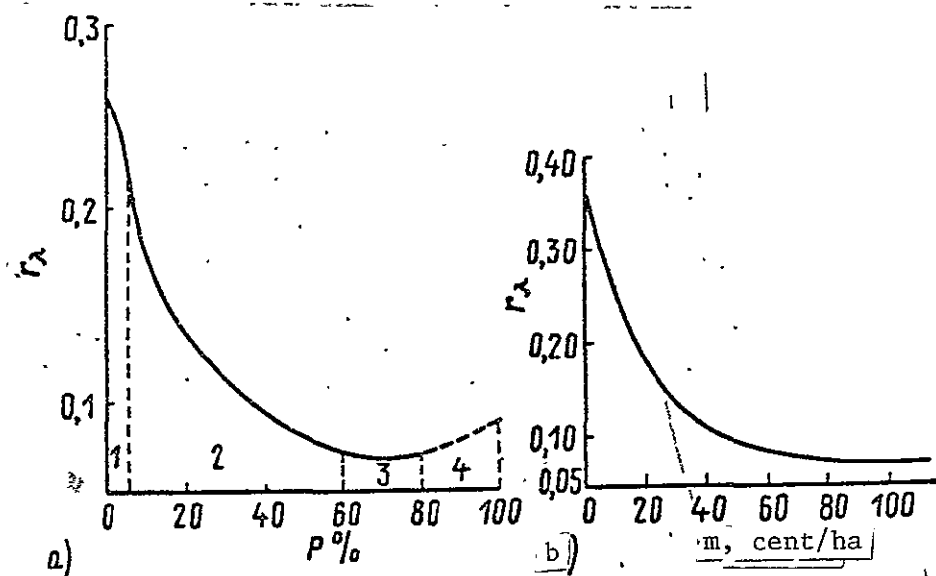


Figure 3. Forms of relation between structural optic parameters of phytocenosis (Belyayeva, Rachkulik, Sitnikova, 1966; Vinogradov, 1970): a - between projecting canopy of xeromesophytic vegetation with complete type of coverage ( $P$  in %) and  $r_\lambda$  and b - between productivity of ephemeral-wormwood communities ( $m$  in centner·hectare<sup>-1</sup>) and  $r_\lambda$  in the orange-red part of the spectrum at  $\lambda$  0.59-0.72 micron.

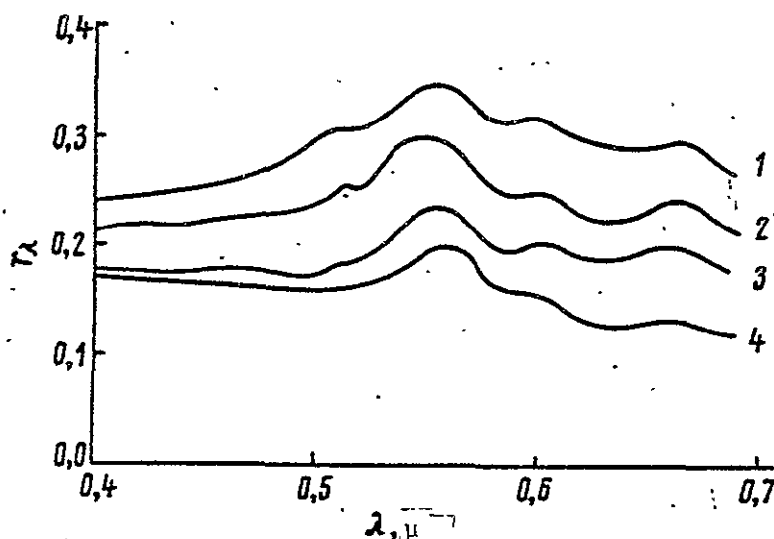


Figure 4. Spectral brightness ratios of various morpho-ecological groups of vegetation measured from manned spacecraft Soyuz-9 in the 0.41-0.69 micron interval (Kondrat'yev, et al., 1972): 1 - semidesert, 2 - meadow-steppe, 3 - meadow, 4 - meadow-swamp.

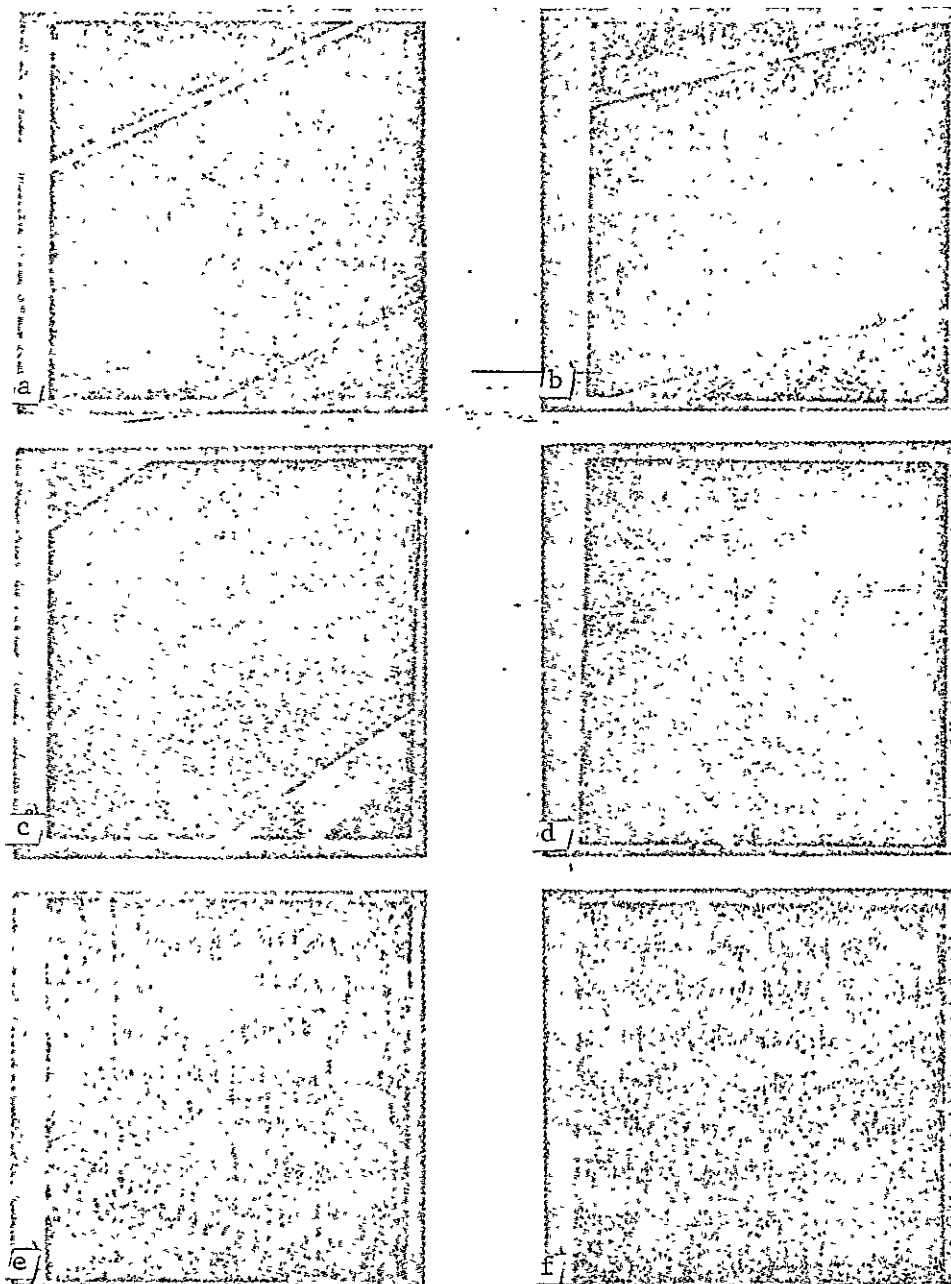


Figure 5. Seasonal changes in the photographic image of agricultural lands; a - freshly plowed fields, b - crops in first leaf stage, c - in straw development stage, d - in earing stage, e - in milk-wax ripeness stage, f - stubble.

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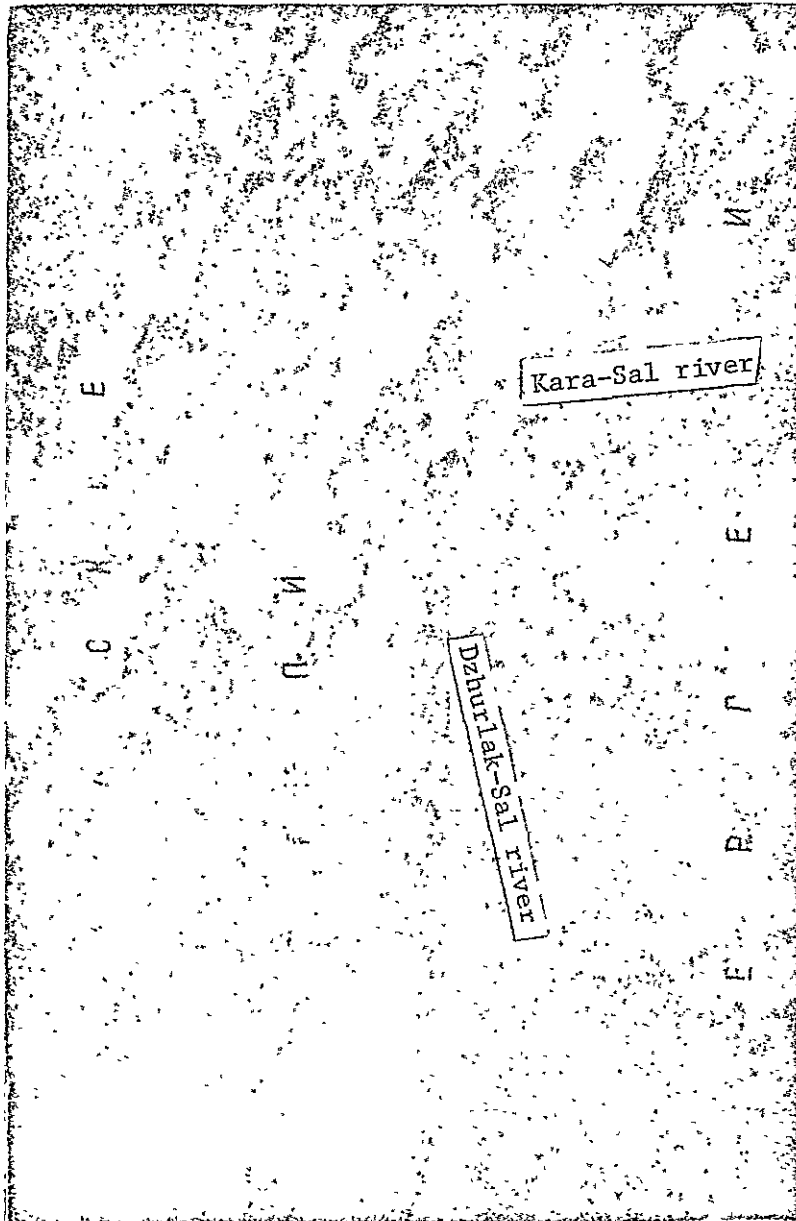


Figure 6. Enlarged portion of black and white photograph of agricultural lands of the Sal'steppes and Yergen' obtained on 15 June 1970 from the manned spacecraft Soyuz-9 (Vinogradov, Lipatov, Sevast'yanov, 1974)

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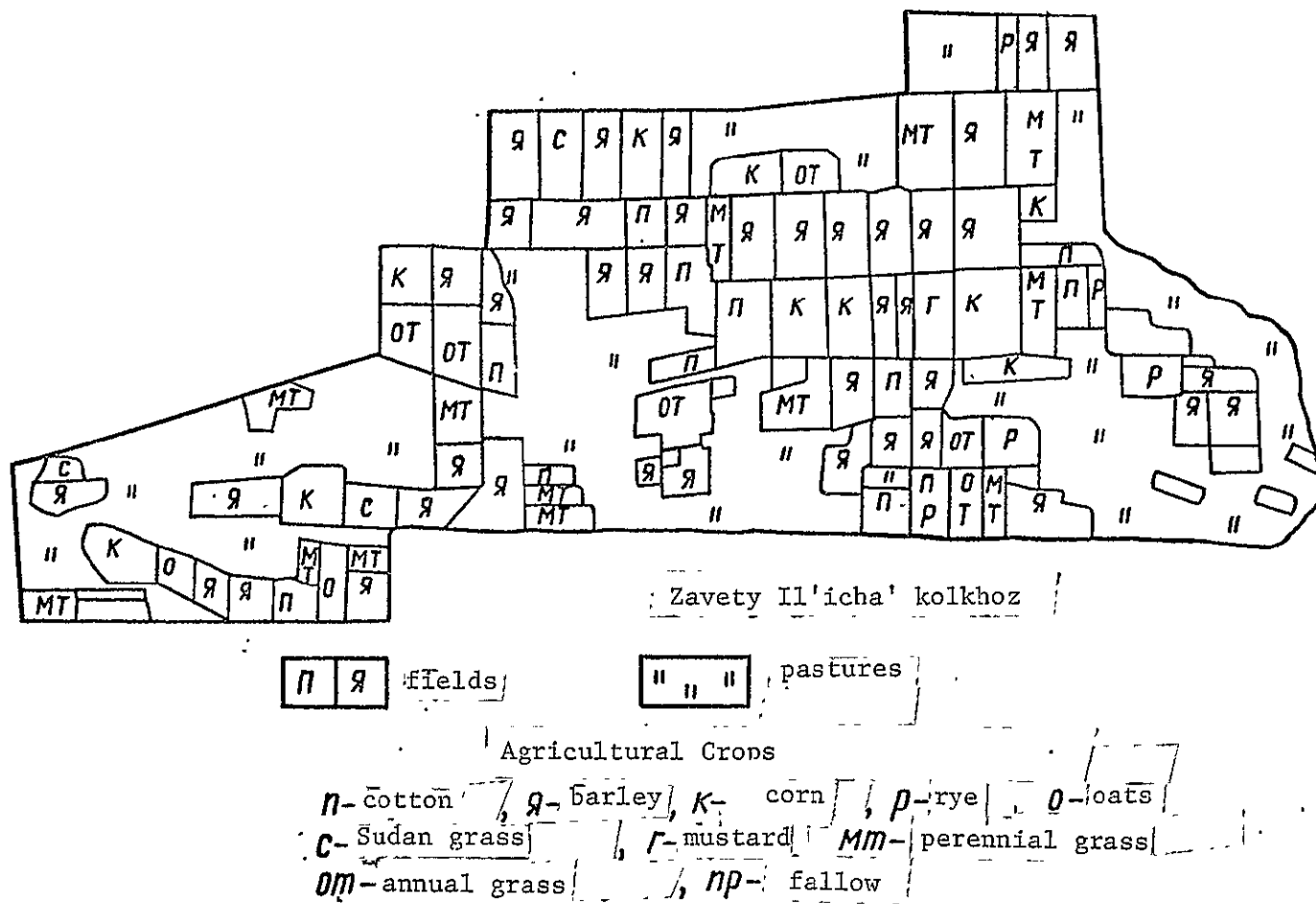


Figure 7. Diagram of intra-kolkhoz arrangement of agricultural lands and crops of a key portion of the Sal'steppes based on a photograph obtained from Souyz-9 on 15 June 1970 (Vinogradov, Sevast'yanov, Serdyukova, 1973-74)



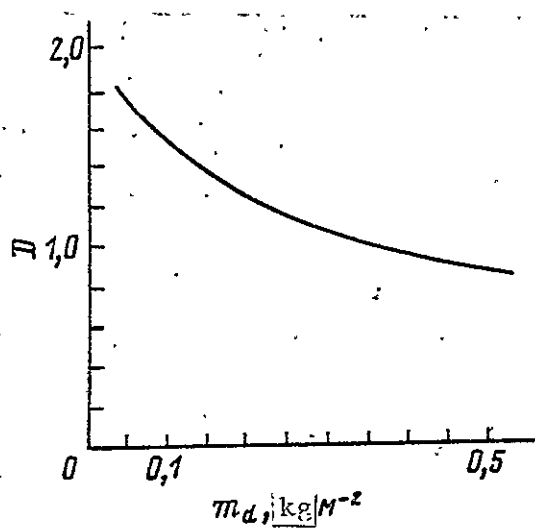


Figure 8. Shape of relation between optic density of negative image D and productivity of semidesert vegetation in early summer in photoactinic interval  $\lambda$  0.57-0.69 micron (Vinogradov, 1970).

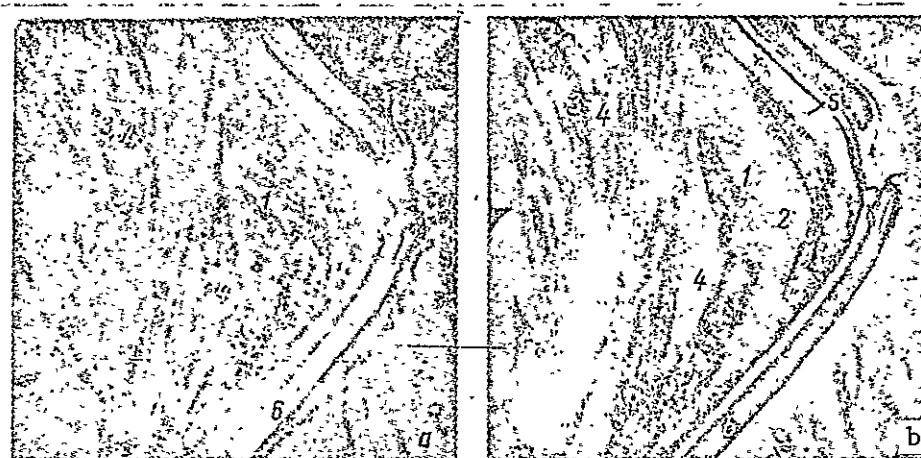


Figure 9. Photographs of water meadow landscape along the Ural River in the northern desert zone obtained in different spectral ranges (Vinogradov, 1966): a — in orange-red band of the spectrum with maximum sensitization at 0.62-0.65 micron and b — with maximum in near infrared band at 0.72-0.74 micron, where 1 — salt crusts with sparse halophytic vegetation, 2 — white wormwood, 3 — sagebrush-couch grass steppe-meadow, 4 — mesophyte-mixed grass-sedge-couch grass water meadows, 5 — hygromesophytic — mixed grass communities in ox bow, 6 — arable lands with moist soil.

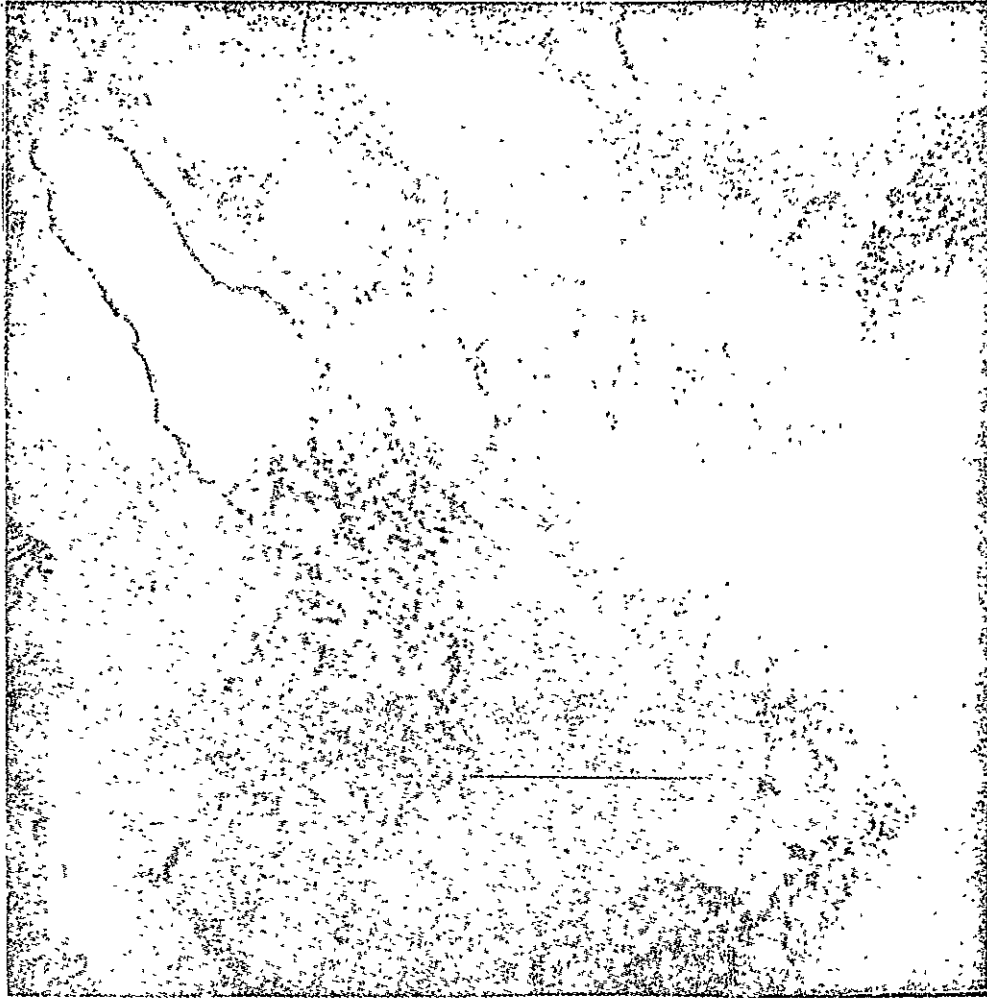


Figure 10 c

Figure 10. Multiband photographs of the Imperial Valley and Salton Sea, California, USA, obtained from manned spacecraft Apollo-9 March 12, 1969, in original scale 1:3 million (Colwell, 1971; Nalepka, 1970); C - infrared film, D - panchromatic film.

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Figure 10 d

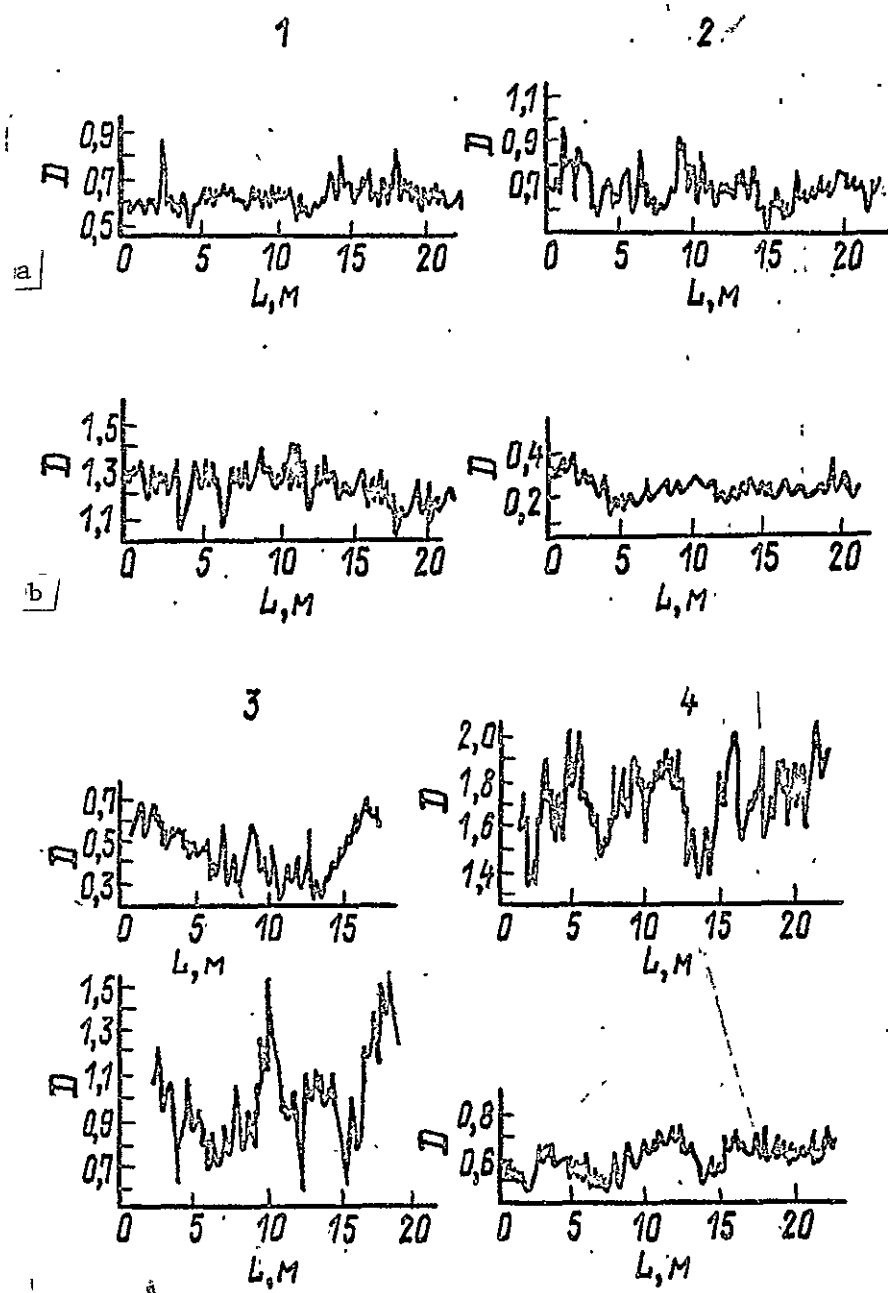


Figure 11. Comparison of densimetric registrograms of identical profiles by multi-band photographs (Vinogradov, 1966): a — in orange-red part of the spectrum  $\lambda$  0.58–0.69 micron and b — in green-yellow part of the spectrum  $\lambda$  0.52–0.62 micron, where: 1 — mesophyt-mixed grass-couch grass meadows, 2 — hygromesophyte-mixed grass-sedge swamp, 3 — shoots of willow on alluvium, 4 — fields with sprouting crops.

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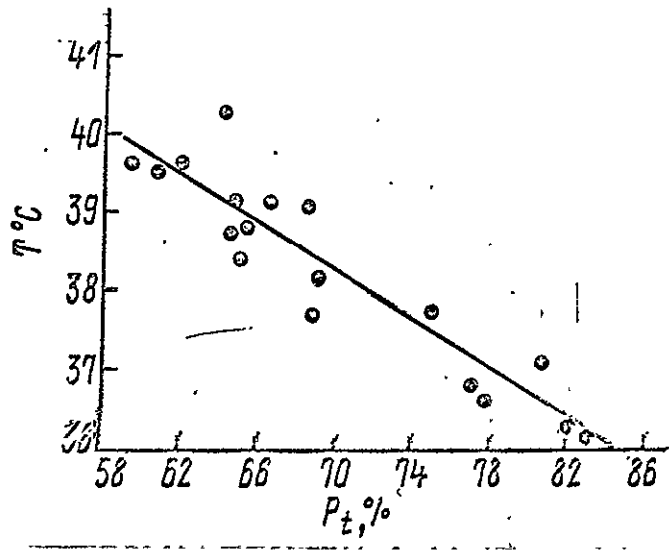


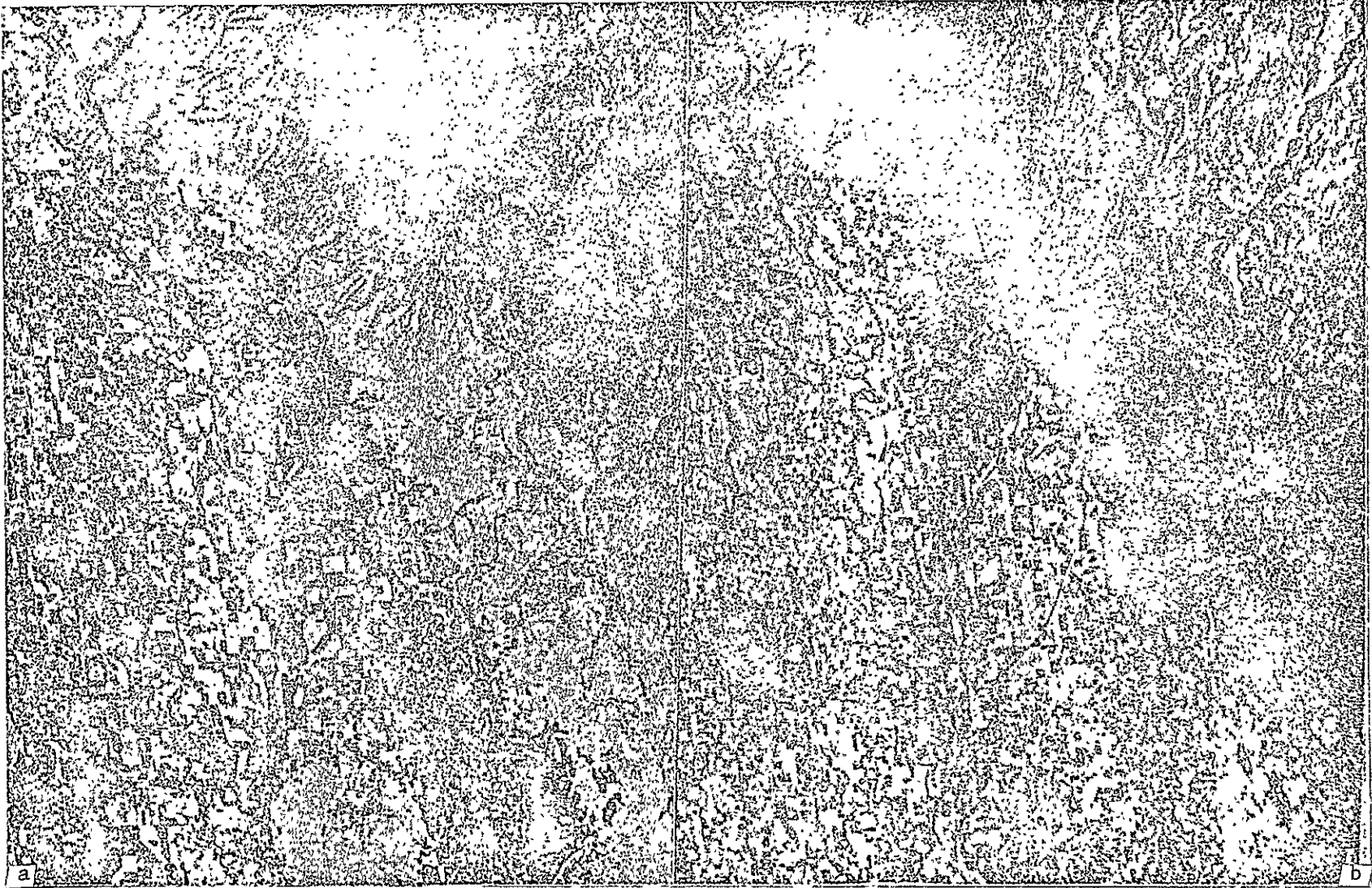
Figure 12. Dependence of thermodynamic temperature of the cotton leaf (T°C) on relative turgor (%) (Holter, 1970).



Figure 13. Infrared image of agricultural lands in southern Sweden at night at  $\lambda$  8-14 micron (Svensson, 1967): 1 - plowed fields, 2 - green crops, 3 - maturing yellowing crops, 4 - settlements.



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Figure 14. Fragments of multispectral images of agricultural lands in the Sacramento River Valley of California, USA, obtained July 25, 1972, from the ERTS-1 satellite (Colwell, 1972). MSS-5 in  $\lambda$  0.6-0.7 micron range and b - MSS-7 in the  $\lambda$  0.8-1 micron range.

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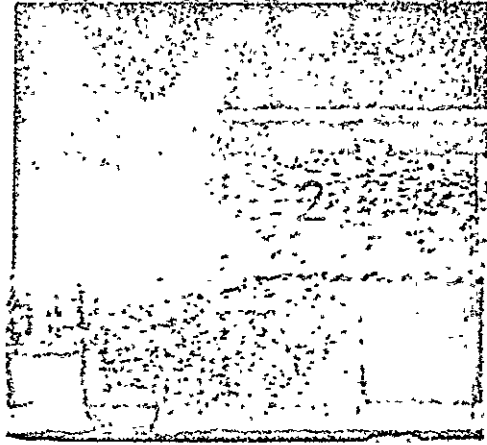


Figure 15, Radiothermal images of agricultural lands from an altitude of 300 m in  $\lambda$  0.55 cm spectral range (Estes, 1973), where: 1 - fields of wheat and barley with dry soils, 2 - fields of cotton with wet soils.

Identification of Agricultural Lands of the Dry Steppe  
by Space Imagry  
(Using the Sal'sk Key Section as an Example)

Ye. V. Glushko

At the present time, accounting for land use is becoming an especially acute /45  
problem in connection with the intensification of agricultural production. The growing demand for more accurate, prompt, regular and easily-analyzed information concerning different types of agricultural lands in scales of administrative regions, oblasts and even USSR republics requires the development of more universal methods of collecting and analyzing information, in particular, the use of remote aerospace sensing of agricultural landscapes.

Study of the possibilities of aerospace surveying has shown the feasibility of its use to solve a number of scientific and practical problems in the area of agriculture. Evidently the use of such surveying will provide the information necessary for solving many problems. Selection of the type of remote sensing is determined by the specific range of questions requiring answers.

Black-and-white photography is used most widely, as it is carried out with the aid of relatively simple, easily operated camera by a method developed in detail for aerial photography. The pictures obtained are characterized by good photometric imagry characteristics, permitting high quality densitometric analysis, high spatial resolution, a wide range of choice of light filters, the possibility of stereoscopic analysis, visual similarity between the image and the objects photographed, facilitating the process of identification, and the possibility of both manual and automatic filming (25).

The use of photographic surveying in agriculture is best for solving the following problems: 1) separating areas of land use, differentiating the basic types of agricultural lands, measuring crop areas and forage lands (3, 6, 7, 12, 14, 15, 16, 17, 22), 2) identifying the composition and condition of agricultural crops (4, 13,

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19, 23, 24, 26) and pasture vegetation (2, 5, 21), 3) separating basic types of soils, determining their degree of salination, moisture content and erosion (1, 9, 10, 11, 18, 20).

In this article we shall discuss the experience of identification of types of agricultural lands and qualitative evaluation of their condition by space black-and-white photographs of crop lands in the dry steppe zone. We interpreted small-scale photographs of agricultural landscapes of the Sal'sk dry steppe agricultural region made on panchromatic film from the "Soyuz-9" spacecraft by cosmonaut-pilot V. I. Sevats'yanov on June 15, 1970, from an altitude of 228.3 km in original scale at the central point of the image of about 1:7,560,000 with the sun at an altitude of about  $21^\circ$  (Fig. 1). On-site resolution of areal objects of moderate contrast was 200-250 m and linear objects of high contrast -- 50-100 m.

Prints from an original negative magnified to scales of 1:1,000,000 and 1:250,000 were used to identify agricultural lands. Recognition of elements of the photograph was aided by data of small-scale aerial surveying performed synchronously with the satellite survey and maps of farm land use for 1970, as well as ground observations of the condition and composition of agricultural lands for 1970 and ~~1972~~.

As a result of ground observations during the 1970 survey from the satellite subsatellite reconnaissance examinations were made of agricultural lands, the composition and condition of agricultural crops and pastures. These data were later used for visual interpretation of the photographs, on the basis of information on actual conditions of the surface during the period of the survey. Following ground observations in 1972 made it possible by comparing agricultural lands with their photographic image to determine identification signs and estimate the degree of their recognition on small-scale photographs from space. /46

The region studied covers a total area of about 130 thousand hectares and includes lands of the "Im. Lenina" and "Zavety Fl'icha" collective farms and the "Pervomayskiy" and "Privolenskiy" state farms in the Rostov Oblast. The territory is located in the dry steppe zone, in an area of moderate continental climate (continentality increases from west to east, reaching 70%). The January mean temperature is  $-7^\circ\text{C}$ , the minimum --  $-15$ - $-20^\circ\text{C}$ , the June mean is  $+24^\circ\text{C}$ , the maximum --  $+38$  -  $+42^\circ\text{C}$ . Precipitation does not exceed 400 mm per year, relative humidity is 51%. The distribution of precipitation is extremely uneven, 40% falls in winter, 25% in spring,

38% in summer and 2% in the fall. The rainless period in drought years can last 60-70 days.

Under these conditions, on plains formed by Quaternary loessic loams, were formed chestnut alkaline soils and on slopes among them appear steppe "solonets." Meadow-chestnut dark soils and steppe "solonets" developed in suffusion sinks. In river valleys, meadow-chernozem and meadow-chestnut soils were formed in middle and upper Quaternary alluvial deposits and steppe "solonets" are found.

The vegetation cover is extremely uniform. Natural vegetation was represented by needle grass-feather grass dry steppes. As a result of plowing up of a large part of the area, native vegetation has been replaced by secondary wormwood-needle grass communities and annual and needlegrass groups. Vegetation grows most intensively in the spring and first half of the summer, in the hot months it dies down and during the heavy rain period in late summer and fall it revives.

Wormwood-needlegrass communities predominate in chestnut saline soils in watershed sections. Needlegrass-couch grass communities prevail along gullies and river valleys in meadow-chestnut soils. In unplowed areas irrational pasturing of cattle causes a degradation of the plant cover. In individual regions, primarily along cattle trails, there is a predominance of wormwood, needle grass, sagebrush and thornbush groups.

The Sal'sk key section is located in a region of intensive farming with a predominance of grain and with a widely developed livestock industry. Agriculture is concentrated in the western part, areas of plowed land are markedly reduced in the east. Unirrigated agriculture prevails, only individual small sections around ponds are irrigated. Grain crops include: spring barley, winter wheat, corn, oats, rye, Sudan grass, annual and perennial grasses (alfalfa, wheat grass, esparto). Saline lands of watersheds, dry gullies and river valleys are given over to pastures, hay meadows and cattle trails. The harvest in hay meadows is 3-5 centners per hectare.

In accordance with the established list of agricultural lands (8), on small-scale photographs of the area within the resolution limits of the picture, it was possible to recognize: land use boundaries, agricultural crops, fallows, pastures, cattle trails, the gully network, ponds, settlements and main lines of communica-

tion. We could distinguish clouds and their shadows, masking the image of agricultural lands. On the photograph these cover less than 1% of the area surveyed. Clouds are characterized by a light tone and shadows by a thick dark-gray, less often a darkish-gray tone and they are well differentiated from the Earth's surface in shape and image tone.

The following characteristics of the photo image were used in visual identification of the pictures: 1.) photo tone, configuration, size, recurrency and texture of specific elements of the image, 2) predominant tone and pattern of features, 3) structure of the image, boundaries of features and their size. Besides these characteristics, we used such indexes as relief, soil conditions and phenological condition of the plant cover.

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Agricultural lands were identified visually on paper photo prints by a combination of geometric signs and image tone. The tone is established by the degree of blackening of the photo print using a seven-point scale of black-and-white tones. The phototone of the image of a group of agricultural lands was evaluated using the following characteristics:

- 1) average tone of image ( $\bar{D}$ ),
- 2) dispersion of average tone of image ( $\sigma_D$ ),
- 3) frequencies of predominant gradation of image tone ( $F, \%$ ).

By the combination of densitometric signs, all isolated agricultural lands were combined into four groups: 1) agricultural crops and fallows, 2) waterless valley pastures and cattle trails, 3) water meadow pastures and hay meadows, 4) settlements (Fig. 2). For the isolated groups of agricultural lands we plotted a graph of the distribution of blackening levels on the photo print from the darkest tones to the lightest (Fig. 3). Comparison of imagery characteristics showed that a certain more or less narrow tonal interval is typical of each group of agricultural lands in which the majority of features appear in this tone. As follows from the graph, areas of distribution of average tones on the image of the first three groups of lands show practically no overlapping, which indicates the possibility of their recognition by predominant tone with reliability approaching 100%. Overlapping areas of the first and fourth groups of lands do not prevent their differentiation, as fields and settlements are correctly recognized by shape, type of boundaries, structure of the image and location.

Satisfactory brightness contrasts of the photo image for recognizing types of land are provided by the varied phenological state of vegetation in individual agricultural lands during the survey period (mid-June).

Images of individual lands encountered infrequently (gardens, melon fields, permanent fallows, hay meadows and forest bands) are not considered because of insufficient data.

Land use boundaries of collective and state farms were reliably determined, taking into account such reference points as field borders, elements of the hydrographic network, roads and forest belts. In cases when land use boundaries were intersected by pasture areas, appearing as a homogeneous tone, boundaries were distinguished by using cartographic data of collective and state farms.

Fields of various agricultural crops appear in the photograph as a mosaic of rectangular fields oriented meridionally. On the space survey practically all fields with area from 400 to 16 hectares are recognizable, that is, those with sides over 400 m. However, it is extremely difficult to determine the internal structure of fields because of the super-small scale of the photograph. Fields have distinct and even boundaries. The predominating tone is dark-gray; however, depending on composition of the crops, phenological development, soil conditions and agrotechnology, the image tone of fields varies from gray to dark-gray. The shape and size of field areas as a whole depend on relief, as they are limited by watershed spaces. In the immediate vicinity of gullies, outlines of fields repeat their curves.

Eroded fields are recognized on the photograph by uneven bands of a lighter tone on the surface of fields. Irrigated lands are limited to small areas in the bottoms of gullies near ponds. On the picture they are not identified because of the insufficient territory occupied. Fallow areas are not widely distributed. The current year's fallows have basically a homogeneous dark-gray tone, last year's are darkish gray.

Agricultural crops and fallow sections occupy an average of 60% of the territory, to the east plowing is markedly reduced. 70% of the land on the "Zavety Il'icha" collective farm is cultivated, 64% on the "Im. Lenina" collective farm, 54% on the "Pervomayskiy" state farm and 53% on the "Privolenskiy" state farm.

Perennial fallows are very uncommon in the region studied. They were not identified because of insufficient size and insignificant tonal differences with fields and between perennial fallows and pastures.

Unplowed lands of collective and state farms are almost completely occupied by pastures, hay meadows and cattle trails (38% of territory). Dry valley spring and summer pastures occupy the least fertile lands of watersheds, their slopes and the upper reaches of gullies. On the picture they are characterized primarily by a homogeneous lightish-gray tone. Insignificant tonal differences in the image of pastures are primarily due to different degrees of cattle use. The more the plant cover is grazed by cattle and the more deformed the surface layer of soil, the lighter the tone of the image. Maximum damage is reached on cattle trails.

A cattle trail leading from east to west along the southern border of the "Provolenskiy" state farm and the "Zavety Il'icha" and "Im. Lenina" collective farms is traced for over 50 km and is distinguished on the picture by a thin light-gray strip with diffuse boundaries. Adjacent sections of pastures appear in a slightly darker photo tone than cattle trails, but lighter than the basic pasture areas.

Dry valley hay meadows are rare and on the space image of this season are not differentiated by predominant tone from pastures.

Water meadow pastures and hay meadows, adapted to large gullies and river flood lands, are also easily distinguished against a background of dry valley pastures. Along bottoms of gullies they are represented by needle grass-couch grass communities and appear as narrow twisting gray bands with moderately contrasting boundaries. The main occupants of river flood lands are meadow-bog, meadow and meadow-saline communities. On the picture they are wider and less twisting bands of a darkish-gray tone with distinct boundaries.

A slight thickening of the plant cover, connected with a high ground water level, is well reflected on the photo and indicates soils with the greatest moisture content.

Field-protecting forest bands 10-25 m wide, easy to spot visually from the satellite, can almost nowhere be identified on the photo image, as their dimensions are an order less than the spatial resolution of photography. But their presence

makes the image of field boundaries more distinct.

The ravine-gully network is distinguished on the photo primarily indirectly, by change in the character of the plant cover. Reduction of the thickness of the network from west to east is easy to trace on the photograph.

The majority of ponds are poorly identified. They are distinguished by low-contrast patches slightly wider than the strip of the gully, separated from it by a light cross-strip of the dam. The image tone of ponds varies from gray to dark-gray, depending on the turbidity of the water and with very slight turbidity — on the depth and degree of silting of the bottom. The shallowest ponds with a thick layer of silt and smooth bottom surface appear as a homogeneous gray tone. With increased depth of reservoirs, decreased turbidity of the water and thinner layer of silt, the tone of the image changes to darkish and dark-gray.

Settlements occupy less than 2% of the area. They are represented primarily by individual villages and farms. On the photograph settlements are distinguished by darkish-gray textured isolated patches of uneven or long drawn out shape with moderately contrasting boundaries along a band of gully or river channels against a lighter background of surrounding highly trampled vegetation. The largest graded roads appear as straight light lines against a background of pastures and among field areas.

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Study of the possibility of identifying agricultural lands on prints of the original negative (scale 1:7,560,000) showed that on a working scale of 1:1,000,000 the basic groups of lands are reliably distinguished:

agricultural crops and pastures are clearly differentiated;

boundaries are easily recognized and both large tracts and separate fields can be measured;

dry and water meadow pastures are clearly differentiated

the largest settlements are distinguished.

For more detailed characterization of the locality a working scale of 1:250,000, was more informative, providing more specific qualitative and quantitative indexes of each group of agricultural lands. In this scale within limits of photo resolution in this area it was possible to:

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determine the degree of soil erosion in fields and pastures,  
determine the degree of trampling of pastures,  
update boundaries and areas of distribution of water meadow pastures and  
hay meadows;

distinguish the moistest soils in gullies,  
update boundaries and areas of artificial reservoirs,  
determine fluctuations in the water level of ponds,  
compare the turbidity of water, depth and degree of silting of the bottom,  
determine boundaries and areas of settlements,  
update the location and extent of large roads.

In order to determine the reliability of identification of agricultural lands on a small-scale panchromatic photograph, we compared results of identification with farm land use maps in the period during the space survey and ground observations of 1970 and 1972 (Fig. 4). As a result, it was established that identification of categories of agricultural lands was basically correct. However, land use maps give a more schematic picture of crops than photographs. Individual fields are indicated on maps in a different place or have a different configuration than on photographs or in the field. In addition, obvious differences are noted in field boundaries within tracts of plowed lands. Calculation of planted areas on space photographs and land use maps showed the following differences:

on the space photograph of 510 fields, 18 noted on land use maps could not be identified. Unidentified fields vary in area (average field area about 100 ha) and comprise 3.1% of all planted areas. As a check showed, the main part of unidentified fields located alongside pastures are not used for agricultural crops, being abandoned fields, perennial fallows and fields with seeded perennial grasses serving as pastures, which resemble pastures in image density and are not differentiated.

At the same time, 32 fields were found on the space photo which were not shown on land use maps. These fields also vary significantly in area (average area of field about 120 ha) and comprise 6.3% of all planted area. The existence of 3730 hectares of planted area in addition to that noted on land use maps indicates a tendency toward their expansion by collective and state farms at the expense of pasture sections. Underestimation of cultivated areas occurs as the result of out-of-date maps on which all the yearly changes in planted areas cannot be reflected.

## CONCLUSION

Interpretation of space panchromatic photographs in original scale of 1:7,560,000 magnified 7.5 and 30 times gives satisfactory results in identification of all basic agricultural lands located in the given territory. Distinction of such lands as agricultural crops and pasture sections, dry pastures, wet meadow pastures and hay meadows, cattle trail strips and settled land was carried out with reliability approaching 100%.

Surveying in mid-June appeared most favorable for identifying agricultural lands as light contrasts of the vegetation cover of the dry steppe zone are maximum at this time.

As the results of identification show, small-scale panchromatic photographs can be used successfully in revising farm land use maps. Ground observations provide map revision every 6-8 years. With the use of repeated aerial surveys, maps can be corrected every 2-3 years. Periodic photography of agricultural regions from space will make it possible not only to record all yearly changes in the location of agricultural lands for modifying land use plans, but also to control the accuracy of their implementation by individual farms.

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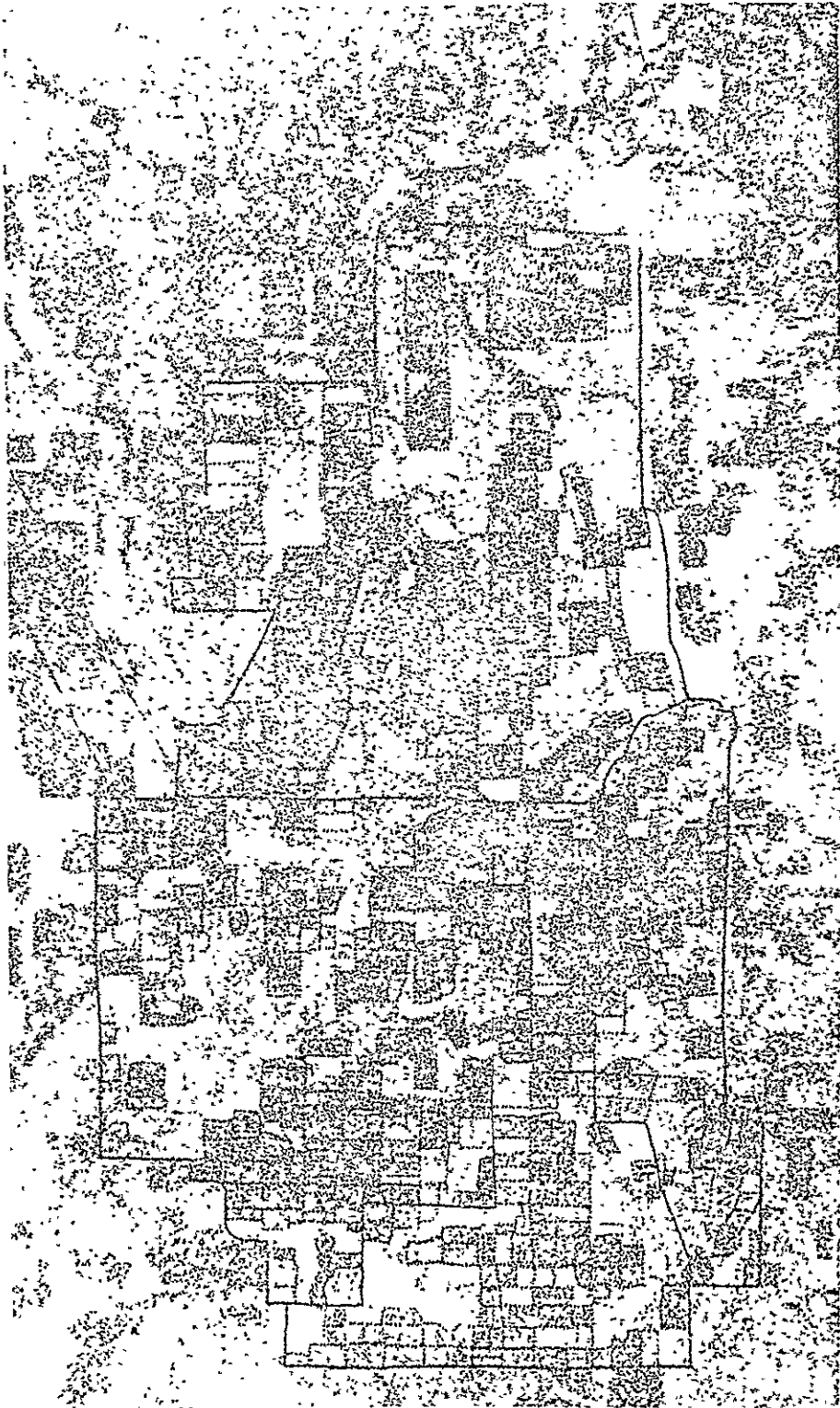


Figure 1. Fragment of small-scale photograph made from " Soyuz-9" on June 15, 1970.

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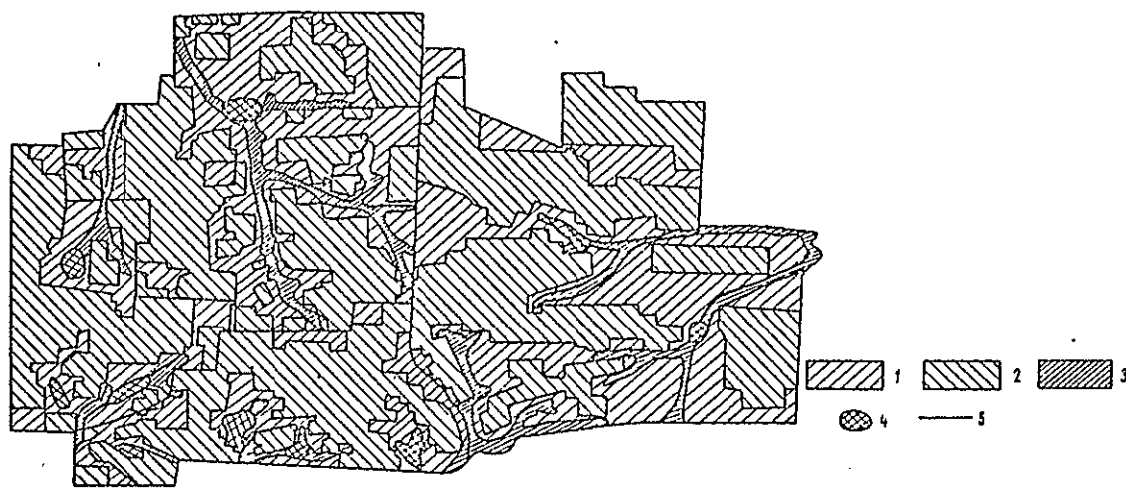


Figure 2. Summary land use map of "Zayety Il'icha" and "Im. Lenina" collective farms and "Pervomayskiy" and "Privolenskiy" state farms, compiled as the result of identification of space photographs. Legend: 1) agricultural crops and fallows, 2) dry pastures and cattle trails, 3) water meadow pastures and hay meadows, 4) settled areas, 5) land use boundaries.

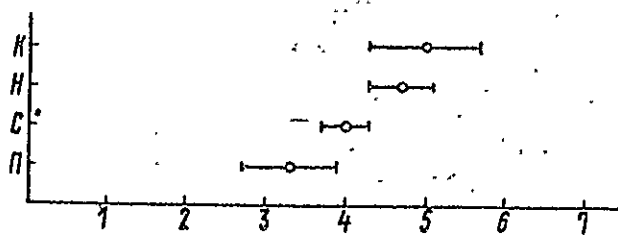


Figure 3. Average values (o) and dispersion of blackening of the positive image of groups of agricultural lands. Tone gradations of positive image: 1 - light, 2 - light gray, 3 - lightish gray, 4 - gray, 5 - darkish gray, 6 - dark gray, 7 - dark. Groups of agricultural lands: K) agricultural crops and fallows, H) settled areas, C) wet meadow pastures and hay meadows, II) dry pastures and cattle runs.

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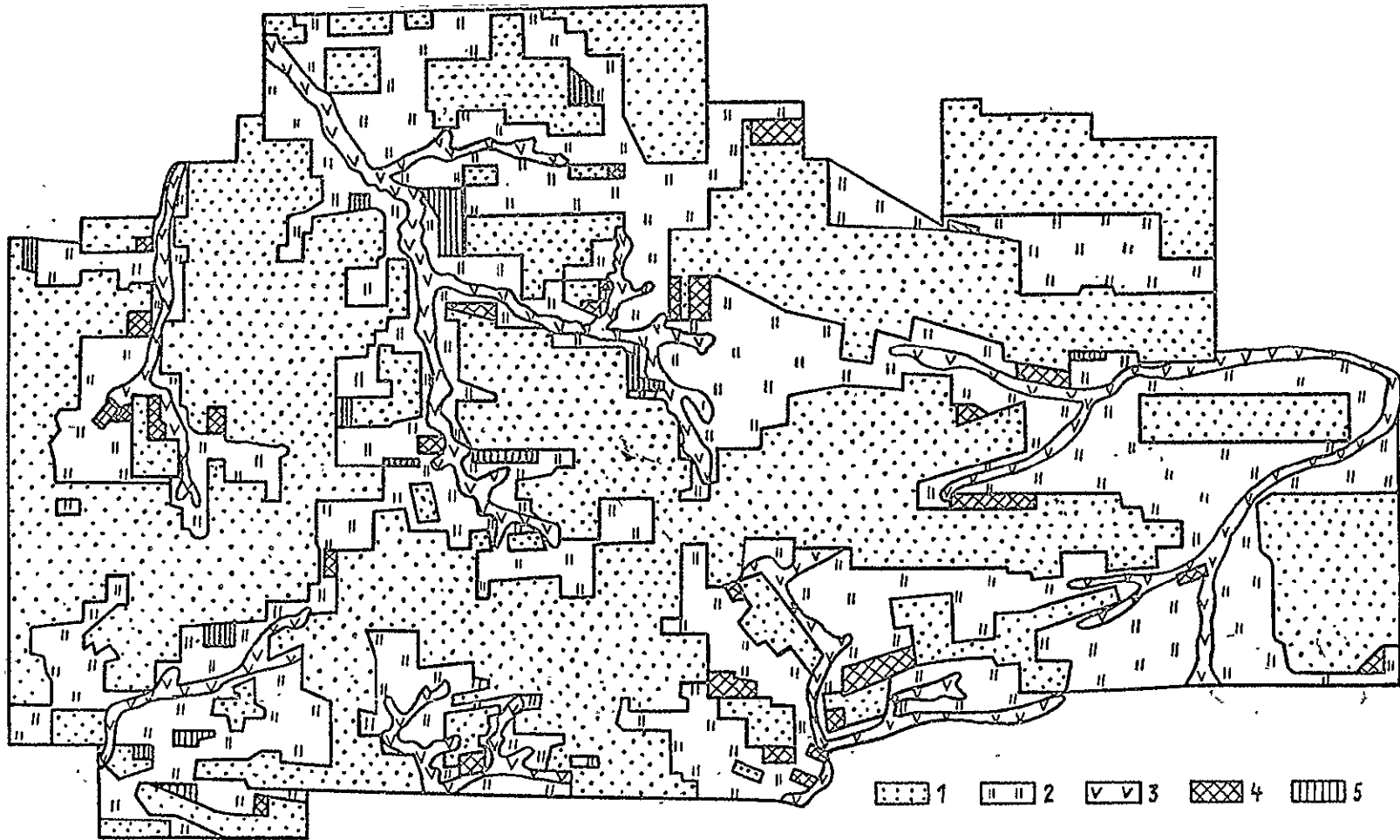


Figure 4. Outline map of comparison of identification of photographs from "Soyuz-9" and land use maps. Legend: 1) agricultural crops and fallows, 2) dry pastures and cattle runs, 3) wet meadow pastures and hay meadows, 4) fields identified on photograph but not shown on land use maps, 5) fields shown on land use maps but not identified on photograph.

The Possibilities of Remote Sensing of Potato Diseases  
in the Near Infrared Band of the Spectrum

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A. V. Alyab'yeva, D. S. Bulatov, E. D. Tamitskiy and V. S. Khrutskiy

Aerial photography as a method of investigating and mapping a district is widely used at present in various branches of science and practice involved with studying natural resources. In our country this method has won recognition in various studies concerned with investigation of the Earth, especially its plant cover. Scientific prerequisites indicating the possibility of obtaining additional information on vegetation in the near infrared range of the spectrum were laid down by the fundamental work of Ye. L. Krinov (1947). He proved the possibility of detecting differences in objects by means of photography in the invisible infrared band. The first spectrozonal films, developed under the direction of A. N. Iordanskiy (1955), were the actual technical means of using this possibility on productive scales.

The studies of reflection spectra of numerous objects, conducted by L. A. Mukhina and Ye. K. Kozlova (1966) made it possible to systematize objects by curves of spectral brightness, as well as suggested a method of calculating spectral bands and other photographic conditions, optimum for detecting objects on a photograph. These works created the scientific and technical base for broad introduction of the method of spectrozonal aerial photography into agricultural practice, especially effective in studying the plant cover, particularly phytopathological symptoms.

Vegetation, as a rule, is characterized by significant reflection in the spectral band above 750 nm (the so-called Wood infrared effect). Numerous workers have established that different kinds of plants, depending on their ecological group, form of life, age, relation toward loss of moisture by leaves have different ratios of spectral brightness (SBR) in the infrared zone. As a rule, conifers have less reflection in the infrared band than leaf-bearing plants, cereals less than

mixed grasses, unhealthy and infection-damaged plants less than healthy.

Soviet works touching on the prediction of plant diseases by change in the SBR in the infrared band also indicate the theoretical possibility of detecting phytophthora disease (late-blight) in potatoes in the early stages of development. Thus, in the work of N. G. Kharin, R. A. Bogoyavlenskaya and R. A. Kolovskoy (1965), who measured the spectral brightness of healthy and fungus-damaged leaves (potato, poplar, etc.), it is established that under the effect of pathological factors the shape of the curve of spectral brightness changes in infrared rays, which cannot be seen by the human eye.

However, more specific data on the ratio of spectral brightness in damaged leaves and the typical (narrower) band of the spectrum in which the curve of spectral brightness changes have not been obtained.

Causes of change in the brightness of the light reflection of disease-damaged plant leaves are deep physiological changes in leaf cells and their loss of turgor. According to the data of V. F. Kuprevich (1947), V. Lilli and G. Barnet (1953), and B. A. Rubin (1963), fungi-parasites cause serious changes in the vital activity of the host plant, destroy chlorophyll-bearing parenchyma, repress the synthesis of the protein base of plastids and cause significant changes in the water conditions of the plant.

When leaf tissues are damaged by the phytophthora pathogen, first disturbed is the water-gas balance of the plants, determined by the value of its water-gas component. It is this disturbance of the water-gas balance of the plant which reduces the reflection of light energy by leaves in the near infrared band of the spectrum (700-800 nm), invisible to the eye (M. P. Perevertun, 1957). Further loss of turgor by leaves, destruction of chlorophyll, carotenoids and pigments of tissues cause a change in the reflective capacity of leaves in the visible part of the spectrum in the 300-725 nm interval of wavelengths. /56

Accumulated factual material on the spectral reflective capacity of ailing and healthy plants has made it possible to suggest that infra-panchromatic aerial film can reveal differences in brightness in the infrared band of the spectrum.

Development of technical conditions for aerial photography in order to detect centers of disease damage in plants required solution of the following problems:

1. Establish quantitative differences in the reflective capacity of healthy plants and those damaged by various diseases and the specific spectral band typical of these diseases.
2. Trace changes in ratios of spectral brightness in time (days after infection).
3. Determine difference of optic densities  $\Delta D$  for the image of healthy and damaged leaves.
4. Test possibilities of infra-panchromatic film SN-6M for revealing sections damaged by late-blight.

Studies were conducted under laboratory and field conditions by the Scientific Research Institute of Potato Culture in 1973-1974 (Director — A. S. Volovik), together with the department of aerial photo methods of the State Institute of Land Resources.

The objectives of the laboratory test included the following: a) determination of the reflective capacity of healthy leaves and leaves damaged with fungus diseases (phytophthora and rhizoctonia), b) that of leaves damaged by virus infection causing the leaves to curl up, c) that of leaves damaged by herbicide burn.

Artificial infection of potato leaves with Phytophthora was conducted during the budding period of the plants by the method developed by N. A. Dorozhkin and S. I. Bel'skaya (1967) using microchambers. Infection was produced with a suspension of fungus (Phytophthora infestans De Bary) with 10-15 conidia in the field of view of the microscope at low magnification  $\times 10-20$ . Drops of the fungus suspension were covered with a special microchamber for 12 hours and then moist conditions were created by covering the plants with polyethylene covers.

For infecting potato plants with Rhizoctonia, a culture of the fungus Rhyzoc-tonia soloni (Kühn) was injected into the soil before tuber planting, calculated at: one Petri dish of ten-day culture per 1 liter vessel. Plants damaged by curl-



ing of their leaves were selected visually and tested seriologicaly for the presence of virus "M." .

To obtain data on the spectral reflective capacity of potato leaves under laboratory conditions we used a SF-4A spectrophotometer with an attachment for reflection. The technical design of the instrument made it possible to measure ratios of the spectral brightness of leaves in the spectral range from 390 to 1200 nm, with an accuracy of  $\pm 2\%$ . Design characteristics of the instrument only permitted measurement of detached leaves; therefore, in advance we studied changes in light reflected by the leaf after its removal from the bush with the course of time.

It was established that spectral characteristics of light reflected by the leaf last for 20 minutes and then begin to change markedly due to loss of turgor and withering. This peculiarity necessitated limiting work time with the leaf after its removal to a 10-15 minute interval.

Evaluation of the spectral characteristics of healthy leaves consisted of the following: first, we measured SBR of leaf layers differing in thickness (from one to three), second — we compared the spectral characteristics of tiers of leaves from one and from different plants. For this the plant leaves were divided into four tiers: upper tier of young leaves, middle, lower and a tier of natural atrophy with yellowed leaves. On the first point — measurement of the spectral brightness of one, two and three layers of leaves — no changes were found. In comparing ratios of spectral brightness for the three upper tiers it was found that scattering averages 3-5% in the 400-700 nm zone and 5-10% in the 720-1200 nm zone. An exception is the lower yellowing tier which has poor reflective capacity in the infrared band of the spectrum (Fig. 1).

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The curves of spectral ratios of brightness for the three upper tiers do not differ significantly from curves of measurement scattering obtained in determining the SBR of leaves of one tier of different plants. Therefore, leaves in different tiers differ from each other in reflective capacity no more than leaves of the same tier on different plants.

On the basis of these data it can be asserted that changes in SBR exceeding 5% do not depend on the measurement method and are due only to pathological symptoms.

Measurements of the reflective capacity of plants damaged by *Rhizoctonia*, curled up leaves and burns from the herbicide Reglon established that differences in spectral ratios of brightness in comparison with healthy plants are not significant, i.e. they did not exceed 5%. With increase of exposure of measurements from one to seven days after damage to plant leaves, also no significant differences were found in spectral ratios.

The most interesting data were obtained in measuring the spectral reflective capacity of leaves damaged by *Phytophthora*. In the first three days after infection of the plants no significant deviations in SBR from healthy plants were detected. Also absent were visual signs of *Phytophthora*. On the fourth day weak signs of late-blight appeared on the leaves (barely noticeable dark brown spots) and a simultaneous sharp change in the curve of reflection in the infrared band (beginning at 750 nm).

The jump of SBR in the 700-725 nm range, typical of healthy leaves, was expressed much less strongly in damaged specimens. In five to seven days after infection of the plants, despite significant development of the disease, no further serious difference in reflective capacity of the leaves was found (Fig. 2).

Thus, change in the spectral brightness of damaged plants begins earlier than visual changes in the color of the leaves (turning brown), indicating the possibility of early detection of *Phytophthora* diseases.

The significant difference in ratios of spectral brightness of healthy and ailing plants in the 750-900 nm range, which we detected experimentally, makes it possible to calculate tentatively the difference of optic densities of the negative in order to show the possibility of detecting diseases by photographic means.

It is known that two adjacent objects are perceived on a photograph separately when the difference of optic densities of their image  $\Delta D$  exceeds a certain threshold value  $\Delta D_{thr}$ ; called the "threshold of color separation." The threshold value of optic density at which the eye can reliably distinguish two objects on the negative is considered to be  $\Delta D_{thr} \geq 0.05$ . Calculation of the difference of optic densities for healthy and ailing plants consists of the following:

$$D_h - D_u = \Delta D_{h/u} = \gamma \cdot \lg \frac{r_h}{r_u} ,$$

where  $D_h$  — optic density of healthy plants on negative,  
 $D_u$  — optic density of unhealthy plants on negative,  
 $\gamma$  — coefficient of negative contrast (usually  $\gamma = 1.6$ ),  
 $r_h, r_u$  — brightness ratios of healthy and unhealthy plants.

On the third day after the plants were infected with *Phytophthora* the brightness ratios of healthy and unhealthy plants in the near infrared band are:  $r_h=0.85, r_u=0.80$  (Fig. 2). Then:  $\Delta D_{h/u} = \gamma \cdot \lg \frac{r_h}{r_u} = 1.6 \cdot \lg 1.06 = 0.04$ . Therefore, on the 3rd day after infection the unhealthy leaves are practically undistinguishable from the healthy on aerial negatives developed to contrast  $\gamma = 1.6$ , as  $\Delta D_{h/u} < \Delta D_{thr}$  ( $0.04 < 0.05$ ).

On the 4th day SBR in the 750–800 nm range for unhealthy plants is reduced to approximately  $r_\lambda = 0.5$ , contrast between the photograph of healthy and unhealthy leaves is increased and expressed on the aerial negative by the following density differences:  $\Delta D_{h/u} = 1.6 \cdot \lg \frac{r_h}{r_u} = 1.6 \cdot 0.23 = 0.37$ . This value several times exceeds the threshold of color separation and damaged sections on negatives developed to  $\gamma = 1.6$  will be reliably distinguished against a background of healthy plants.

Our data on spectrometric characteristics of plants and calculations of the difference in optic densities served as the basis for a field experiment photographing healthy plants and those damaged by *Phytophthora*.

We selected a potato plot with various degrees of damage evaluated visually at 1, 2, 3, 4 and 5 points. Photographs were made from an altitude of 18 meters using a Pentacon camera with frame size 6 x 6 cm. We used orange OS-11 and red KS-10 light filters. Results showed that with any of the indicated light filters healthy plants show up pink on the negative. Plants damaged by *Phytophthora* (4–5 points) have a gray-violet color. Intermediate damage is characterized by color transitions from pink to gray-violet. Soil in the photos is light gray.

For practical aerial photography it is possible to use black-and-white infra-chromatic film of the "Infra 830" type with light sensitivity in the most suitable 750–830 nm range. In this case a light filter must be used, cutting off the short-wave zone of the spectrum to 700 nm, which can affect discrimination of damaged

sections. Mass produced spectrozonal film can also be used, SN-6M, for example, which has light sensitivity in this spectral band. The infra-chromatic layer will catch the necessary differences and the light sensitivity of the pan-chromatic layer should be reduced by a thick red light filter of the KS-14 type. Curves of the spectral sensitivity of layers of SN-6M aerial film are given in Fig. 3. From comparing Fig. 2 and Fig. 3, it can be seen that SN-6M film has a rise of sensitivity in the infrachromatic layer in just exactly the spectral zone where the maximum difference in SBR of healthy and unhealthy plants is observed.

### CONCLUSIONS

1. The actual difference in spectral ratios of brightness between healthy potato leaves and those damaged by Phytophthora is established.

2. Maximum differences in ratios of spectral brightness between healthy leaves and leaves damaged by Phytophthora are observed beginning on the 4th day after infection of the plants.

3. Spectrometry results make it possible to distinguish a Phytophthora-specific informative spectral range (750-900 nm) in which the best discrimination of damaged plants must be expected against a background of healthy leaves in aerial photography.

4. The difference of optic densities between healthy and unhealthy plants, shown on the negative, significantly exceeds the threshold of color separation (7 times), making it possible reliably to distinguish unhealthy plants on infra-chromatic negatives.

5. Technical characteristics of aerial film of the SN-6M type permits its use for predicting Phytophthora (late blight) disease among potato plants at various stages of its appearance.

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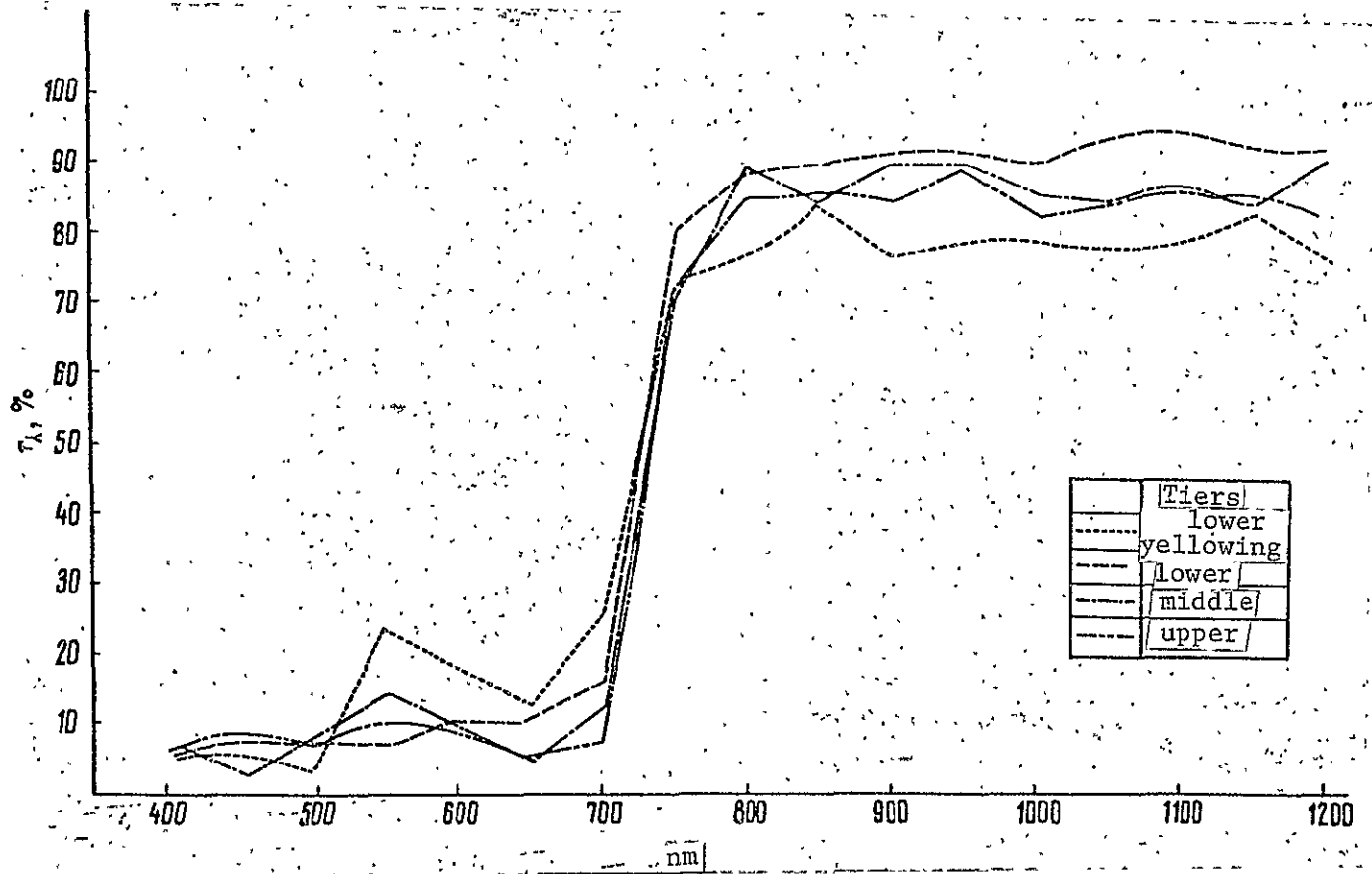
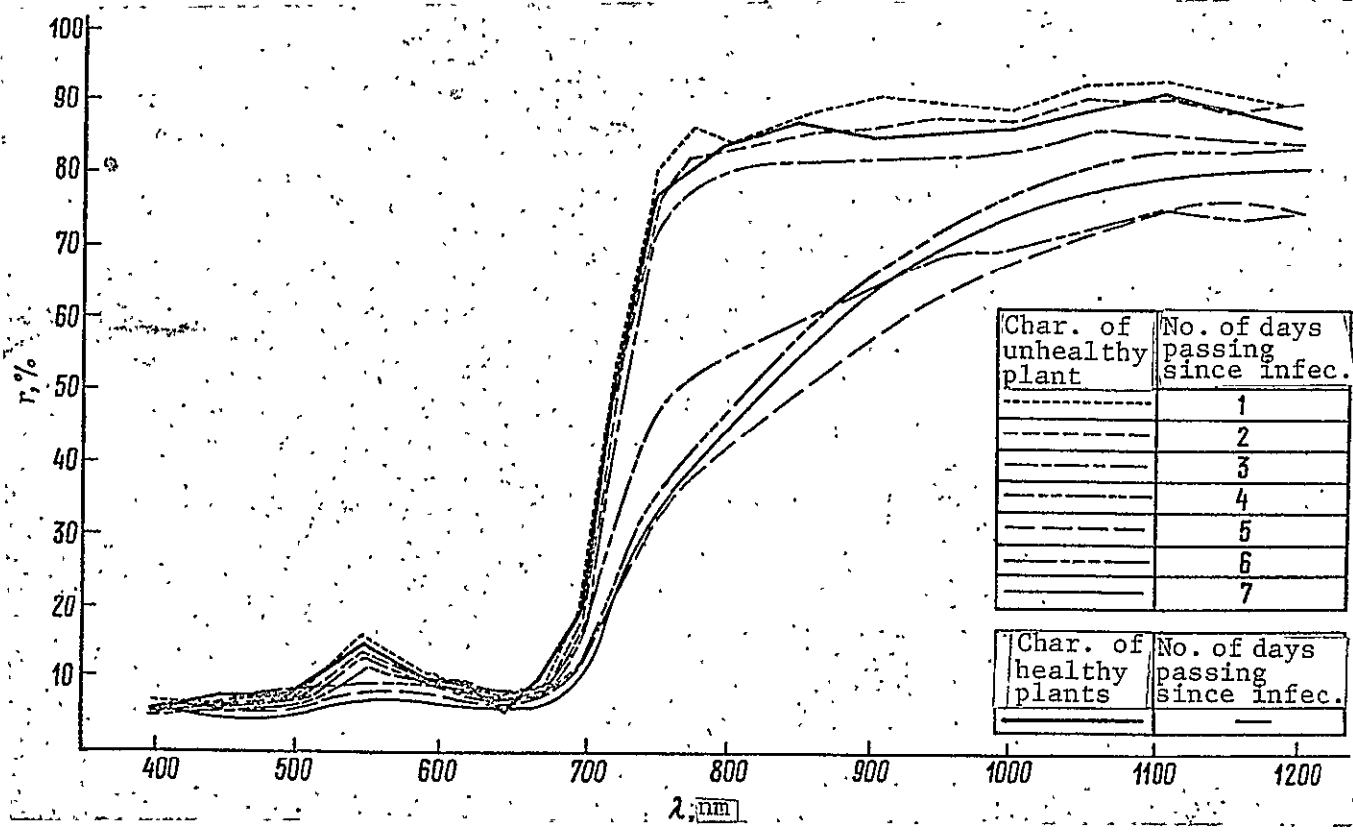


Figure 1. Differences in SBR of healthy potato leaves by tiers



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Figure 2. Differences of SBR in potato leaves depending on degree of Phytophthora damage

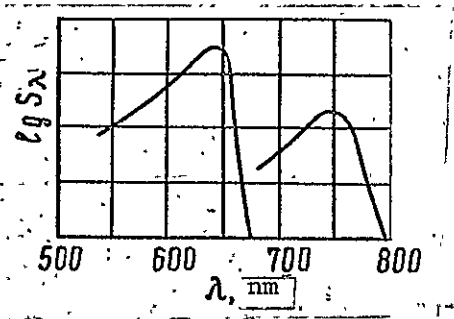


Figure 3. Curves of spectral light sensitivity of spectrozonal aerial film SN-6M

INTERPRETATION OF THE VEGETATION AND AGRICULTURAL LANDS  
OF THE SEMI-DESERT ON MULTIBAND PHOTOGRAPHS  
USING THE TURGAY KEY SECTION AS AN EXAMPLE

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B. V. Vinogradov and Ye. V. Glushko

A great deal of experimental experience of multiband photography of natural resources has now been accumulated using aerial surveying (2, 5, 8, 10, 15, 16, 17) and spacecraft, particularly the "Apollo-9" satellite (6, 7, 9, 12, 18, 19, 20, 21).

Analysis of a large volume of works on decoding aerospace multiband photographs has shown that the main objects of study are soil-vegetation complexes and surface water. A great deal of attention is given to interpretation of agricultural lands, soils, field crops as well as forest tracts and pasture lands for purposes of their study and inventory (6, 7, 10, 13, 14, 16, 20, 21).

In this work we present our experience of interpreting pasture and haymeadow lands in the Turgay key section in the semi-desert zone using multiband aerial survey data. The aerial survey was made in southern Turgay along a latitude profile from an altitude of 5100 m in late summer. On-site resolution of areal objects was 5-10 m, that of high contrast linear objects 2-3 m.

Photographs were made with a system made up of six synchronous cameras with parallel optic axes. Six combinations of films and filters provided surveying in the following spectral ranges:  $\lambda\lambda = 0.44-0.54$  micron;  $\lambda\lambda = 0.51-0.58$  micron;  $\lambda\lambda = 0.50-0.56$  micron;  $\lambda\lambda = 0.52-0.59$  micron;  $\lambda\lambda = 0.59-0.69$  micron and  $\lambda\lambda = 0.67-0.73$  micron. Of these we selected four.

Photos in the  $\lambda\lambda = 0.51-0.58$  micron range made on spectrozonal color film have insufficiently high resolution and are not comparable with images in the other bands. Bands  $\lambda\lambda = 0.50-0.56$  micron and  $\lambda\lambda = 0.52-0.59$  micron are very similar in wavelength intervals. Images of agricultural objects in these bands show no basic differences, therefore, we limited ourselves to one, namely  $\lambda\lambda = 0.52-0.59$  micron.



CHARACTERISTICS OF MULTIBAND AERIAL PHOTOGRAPHY OF TURGAY KEY SECTION

Number of zone	Type of film	Filter	Wave length (micron)
1	Isopanchrome 17	SES 20, ZhS 16	0.44-0.54 (blue-green)
2	Isopanchrome 17	SES 23, OS 12	0.52-0.59 (green-yellow)
3	Isopanchrome 17	KS 15	0.59-0.69 (orange-red)
4	Infrachrome 740	KS 19	0.67-0.73 (far red and near infrared)

In this work we used the central portion of the aerial photographic profile of the Turgay hollow. From the profile we selected four multiband photographs showing the greatest differences in tonal values of objects in different bands: the side of the Turgay hollow and the oxbow lake (Fig. 1), the oxbow channel in the Turgay hollow (Fig. 2), a large depression with a salt marsh and an oxbow lake in the Turgay hollow (Fig. 3), and a sand dune with a dry channel in the Turgay hollow (Fig. 4).

At the same time as the aerial survey, we made ground soil-botanical examinations of this section of the Turgay hollow. Field observations included analysis of the composition and phenological condition of pasture and haymeadow lands, the degree and characteristics of their utilization. As a result, detailed landscape descriptions were compared and preliminary geobotanical maps were made of the territory, which made it possible later to interpret photographs supported by material on the actual condition of the territory at the time of the survey.

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By administrative location the region studied is located in the Dzhangil'din agricultural region of the Turgay Oblast of the Kazakh SSR. The profile intersects individual sections of the area between the Turgay and Ul'kayak Rivers, the accumulative plain with the valley of the Turgay River and the Tosyn-Kum sand dune.

The area between the Turgay and Ul'kayak Rivers is represented on the profile by a mesa-remnant denudation plain and denudation slope to the Turgay hollow on loose Tertiary sand-aleurite-loam deposits. Active erosion-denudation processes, especially widely developed in this section of the watershed sloping plain and valley-gully slopes, led to intense erosion breakdown of the surface and the formation of very pronounced complexity of the soils and plant cover.

The Turgay hollow is an undulating accumulative plain formed by Upper Quaternary sand-loam alluvial deposits on marine Tertiary rock. The modern Turgay River

valley developed in the Turgay hollow. Large oxbow lakes of segmented or oblong shape are located on the accumulative plain.

The Tosyn-Kum sand dune on the east side of the Turgay hollow was formed by modern aeolian-alluvial deposits. Dry channels intersecting it are covered with water only during spring flooding. The undrained water conditions aid in intense salt accumulation. The bottoms of the channels are covered with trash dry salt marshes on high ground and wet ones in lowland bottoms. On both sides of the dry channel, disturbance of the surface of alluvial deposits causes the sandy alluvia to blow away and be redeposited and the formation of dispersed barchan sand dunes. A good ground water supply has allowed alluvial sands to be anchored by vegetation and the hollows to become overgrown with mixed grass-brush communities.

Arid climate conditions are characterized by a mean January air temperature of  $-16^{\circ}\text{C}$  and July of  $+24^{\circ}\text{C}$ . The amount of precipitation is 175 mm per year which equals the level of evaporability, with evaporation reaching 800 mm per year. The present reduction of flood levels is encouraging the encroachment of the steppe onto water meadows. The soil and vegetation cover indicates a shifting of meadow-bog conditions toward meadow.

Zonal light-chestnut saline and alkaline soils are not widely distributed in the Turgay hollow. They are developed on the western slope of the hollow, on the accumulative plain and in the Tosyn-Kum sand dune under a thin plant cover represented by wormwood-cereal communities. Light chestnut alkaline and saline soils developed in a complex with "solonets," occupying over 50% of the area. On the western slope of the Turgay hollow brown alkaline soils are widespread in a complex with "solonets."

Intrazonal automorphous "solonets" develop under conditions of atmospheric moistening and the depth of ground water has no effect. The character of salinization is connected with local soil formation conditions, medium and fine "solonets" and saline steppe soils predominate. At the foot of the western slope of the Turgay hollow and on the accumulative plain both "solonets" and "solonchak" are spread.

On the accumulative plain water meadow and meadow-bog alkaline soils are widespread. On low level flood lands in oxbow lakes with abundant hygromorphic vegetation there is intense accumulation of oxbow alluvium, rich in organic matter,

leading to the formation of peat. Here! meadow-bog alkaline and saline soils are developed. Water meadow alkaline and saline soils develop in medium-level flood lands under thick succulent mixed grass-cereal meadows. High flood land with thin wormwood-cereal vegetation is characterized by high salt accumulation, causing the formation of a flood meadow-steppe carbonate saline soil.

Typical light chestnut alkaline sandy soils are widespread in the Tosyn-Kum sand dune. Encrusted and trash salt marshes formed along the shores of oxbow lakes, on the bottom of lake depressions and in dry river channels.

The vegetation cover varies widely depending on the water supply, the substrate and the degree of salination of the surface. Xerophytic wormwood-cereal desert steppes spread over the western slope of the Turgay hollow and on the accumulative plain. Woody vegetation is limited to river channels and isolated hollows in the sandy desert. Vegetation of poorly-anchored sand is represented by psammophytic mixed grass. In numerous "solonets" and "solonchak" soils the plant cover is limited primarily to halophytic formations.

Desert steppes on zonal light chestnut alkaline and brown alkaline soils in a complex with "solonets" are represented by fragments of various combinations of wormwood and needle grass. Saltbush, wormwood and various other desert plants are developed on deep, medium and shallow loamy and sandy alkaline soils in various combinations.

Osier beds extend along the shores of the Turgay River and the oxbow channel. Reed, rush, horsetail, sedge and other marsh plant communities are developed in oxbow lakes with meadow-bog alkaline and saline soils. Pure reed thickets are widespread along the river channel and along the shores of oxbow lakes. Medium-level flood lands with wet meadow alkaline and saline carbonate soils are covered by succulent meadow vegetation, including couch grass, saltbush-wormwood-couch grass, mesohalophytic-mixed grass-couch grass and saltbush-wormwood communities. Flotsam lies on the lake surface parallel to the shores.

Wormwood, cereals and other plants form communities in the sandy desert on sand hills with light chestnut typical alkaline sandy loam and sandy soils. In wet sandy hollows there are thickets of shrub willows with mixed grass and sand wormwood. In poorly-anchored sands ephemeral-wormwood vegetation is represented

by mixed desert grasses and wormwood communities. There are practically no higher plants in trash salt marshes on the bottoms of lake depressions or in the dry channels. Couch grass meadows have formed along the slopes of the salt marshes.

This region includes extensive pasture and haymeadow lands with potentially great agricultural value. The plant cover of desert steppes serves as a good nutrient base of pasturing cattle. Wormwood-cereal spring and fall pastures along the western side of the Turgay hollow on light chestnut alkaline and brown alkaline sandy loam and loamy soils and "solonets" yield from 1 to 5 centners per hectare. However, pasture lands in this section of the western slope of the hollow are not used to pasture cattle as there is a potential erosion danger. Year-round wormwood pastures on light chestnut soils of the alluvial plain give 3-4.5 centners of dry pasture feed per hectare. Their utilization in pasturage is about 0.5. The percent of their utilization as spring-summer pastures in the spring, at the height of cereal growth, and in the fall as fall-winter wormwood pastures is 100. 50-60% of the pasture is grazed in summer and in winter. Annual selective hay making of pastures is practiced on 10-15% of the area to supplement insufficient hay reserves.

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"Solonets" and "solonchak" soils can also be used as pasture lands. Wormwood-saltbush pastures on natural "solonets" have very low productivity and yield from 2 to 6 centners of low-quality hay per hectare. Feed reserves of autumn succulent saltbush pastures on "solonchak" are even lower, 2-3 centners per year. Therefore, they have no significant effect on the feed balance.

Wet meadows with rough-stem (wormwood-reed) and sedge hay meadows yield from 7 to 20 centners of high-quality hay per hectare. However, meadows are only partially mowed because the flood plain is intersected by river beds and channels, frequently barring access to valuable haymaking lands.

Mixed grass-wormwood pastures in the Tosyn-Kum sandy desert in light chestnut typical alkaline soils are used for winter pasturing of cattle.

The reed thickets of the region are very valuable and promising resources. They are used for hay making and for pasturing cattle as well as raw material for silage. Reeds mowed before earing yield 15-20 centners of hay per hectare and 100 kg of hay contains 40-45 kg of food units. In later phase the reed coarsens and its food value drops. When cattle are allowed to graze in the early phase of

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development, the reed grows well and gives 2-4 cuttings weighing up to 30-35 centers (converted to dry material). Besides the reed is a valuable building material for local construction and a raw material for the cellulose and paper industry.

In identifying agricultural lands, most attention has been given to analyzing the image tone of meadow and meadow-steppe hay lands, thickets of waterside vegetation and pasture soil-vegetation complexes with varying salination and different degrees of surface moisture. For interpretation we used our own field observations of the composition and condition of agricultural lands during the aerial survey, geographic descriptions of the Turgay valley within the profile limits, cartographic material and land use maps of the XXI Congress of the CPSS state farm during the survey period.

Levels of blackening of the photographic print were estimated visually on a seven-point scale of black-and-white tones and instrumentally by microphotometry of negatives according to profiles in certain test sections.

In the analysis of the photos we compared image densities of objects in all four zones and found regular changes in tone from zone to zone for different types of objects. This made it possible to establish "signatures" of soil-vegetation complexes on multiband photographs. We found what additional information is provided by surveying in each narrow zone in comparison with other zones and ordinary black-and-white photography. As a result, we established optimum combinations of zones at our disposal necessary for the most complete characterization of the test objects. /66

Agricultural lands in multiband aerial photographs have the following recognition signs or "signatures."

Pasture lands. Spring and fall wormwood-xerophyte-cereal pastures are developed within the erosion-denudation watershed sloping plain of the western side of the Turgay hollow on brown alkaline soils in a complex with "solonets" (Fig. 5a, 1). Multiband photography transmits well the complexity of soils and vegetation and the erosion pattern of the drainage systems of the hollow. Wormwood-cereal pastures are most typical of the desert steppe subzone with sporadic appearances of weak complexes. Predominant in the composition are: *Seriphidium lercheanum*, *S. terrae albae* Ssp., *S. schrenkianum* and *S. sublessingianum* and xerophytic

cereals: *Stipa sareptana*, *Elymus ruficalyx*, *Agropyron pectinatum*, *Koeleria macrantha*, *Zeymus ramosus*. At the time of the aerial survey the predominant cereal vegetation had finished growing and dried up, but the associated semi-brush still continued to grow.

In pictures in all four zones these pastures are characterized by a predominance of gray-lightish gray tone. The tone of individual elements of the image varies widely from light-gray to darkish-gray. Maximum contrasts between elements of the plant cover are observed in zone 3. Complexity of soils and plant cover, as shown by the photograph, is expressed, but not so clearly as in "solonets." The gradual transition from wormwood-cereal pastures to wormwood-saltbush on "solonets" is traced by change in the ratio of gray patches and lightish-gray tone in zones 2 and 3\*. They are not differentiated in zones 1 and 4.

Year-round pastures of wormwood and associated plants are found in the area of the ancient pediment on the western slope of the Turgay hollow and on the alluvial plain in light chestnut sandy loam alkaline soils in a complex with "solonets" (Fig. 5, a, b, c, 2). Vegetation is a psammophytic variant of desert steppes where besides the above-noted kinds of wormwood-cereal pastures predominate: *Stipa tirsia*, *Koeleria glauca*, *Agropyron fragile*, *Artemisia marschaliana*, *S. sublessingianum*, *Erysiurum lencantherum* and *Achillac gerberi*. Cereals and mixed grasses at the time of the aerial survey had also primarily dried up.

The image is characterized by a reduction of the role of lightish-gray patches corresponding to "solonets," lack of clearly expressed darkish-gray bands of erosion cuts. The predominant tone of the image in all zones is gray and heterogeneous. Discrimination of shallow saline "solonets" by a lightish-gray tone occurs in zones 2 and 3. In these zones boundaries of pastures with wormwood-saltbush vegetation on slopes and those with wormwood-xerophyte-cereal vegetation on the western slope of the hollow are most clearly traced by the structure of the surface image. However, the clearest and most contrasting image of other wormwood pastures is noted in zone 3.

Fall wormwood-saltbush and succulent saltbush pastures are distributed in the area of the young pediment on the western slope of the Turgay hollow on "solonets,"

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\*Note. Zone numbers in the text correspond to zone numbers in the table.

saline "solonets" and "solonchak" (Fig. 5, a, b, c, 3). They are adapted to complexes of deep, medium and shallow "solonets," saline and encrusted "solonchak." The clearly expressed complexity of soils with various degrees of salination of the surface horizon is well transmitted on photographs by a mosaic of small patches of uneven shape in a wide range of blackening tones on the photo print with distinct boundaries. Vegetation in saline lowlands is represented by zone aggregations of individual halophytic species with varying projecting canopy: *Halochemum strobilaceum*, *Frankenia intermedia*, *Anabasis salsa*, *Kochia prostrata*, *Atriplex cana*, *Artemisia salina*, *Salsola laricina*, *Climacoptera brachiata*, *C. lanita*, *C. nitrosa*, *Salicornia europaea*, *Halimione verrucifera*. With a projecting canopy less than 20 (30)% aggregations have practically no effect on the tone of the photograph, however, here and there the thicket cover exceeds this level. The composition of fragments of plant communities of wormwood-saltbush pastures is extremely varied: *Seriphidium lercheanum*, *S. terrae albae* Ssp., *Spauciflorum*, *Kochia prostrata*, *Anabasis salsa*, *Zeymus ramosus*, *Stipa sareptana*, *Festuca rapicola* and *Petrosimonia brachiata*.

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During the aerial survey the semibrush reached maximum growth development and gave shades of dark tones in the orange-red part of the visible band depending on the projecting canopy. At the same time, ephemerals had already dried up, cereals had finished growing and dried up and together with the thinnest fragments of semibrush (for example, *Anabasis salsa* with coverage less than 5-10%) in this spectral interval gave shades of light tones. Thus, variations in the composition and thickness of vegetation, depending on the salination of "solonets," emphasize the complexity of vegetation and soil. In all four zones wormwood-saltbush pastures are formed by a predominant gray tone; however, the tone of individual elements varies from light-gray to dark-gray, creating an unusual patchiness of the image. The structure of the surface and the complexity of soil and vegetation is best transmitted by pictures in zone 2 and especially 3. In zones 1 and 4 "solonets" soils are almost undifferentiated.

Wormwood-psammophyte mixed grass-brush pastures on alluvial sand valleys and hills in the Tosyn-Kum sandy desert (Fig. 5 d, 4). They have the most varied composition of vegetation, which includes cereals: *Festuca beckeri*, *Agropyron fragile*, *Koeleria glauca*; semibrush: *Oligosporus arenarius*, *Onobrychis arenaria*, *Astragalus arenarius*; mixed grasses: *Achillea nobilis*, *Euphorbia segnierana*, *Dianthus squarrosus*, *Centaures pulchella*; trees and bushes: *Salix caspica*, *Elaeagnus caspica*,

*Ceratoides papposa*, and in loose sand such distinct psammophytes as *Ephedra distachya* and *Zeymus racemosus*. The projecting canopy varies from 80-100% in overgrown mixed grass-osier depressions to 0-10% in loose sand. Also nonuniform is the phenological state of vegetation: cereals in large part are already dried up, and mixed grasses, mesophytic cereals and shrubs in the depressions are in full growth development.

The image of the surface is characterized by a combination of small round or oval patches frequently and evenly located along the surface and surrounded by ring-like bands. The round spots correspond to sufficiently moistened hollows with a thick plant cover, represented by wormwood-mixed grass-brush or wormwood-mixed grass communities. The ring-shaped bands correspond to sand hills with weakly-anchored sand. The thin plant cover has no effect on the tone. Hollows with a thick plant cover appear dark-gray in a homogeneous tone with distinct boundaries in zones 1, 2 and 3. The lowest degree of blackening of the photo print is observed in zone 3. In zone 4 there is differentiation of hollows by plant cover. The largest hollows with wormwood-mixed grass-brush vegetation are characterized by a heterogeneous lightish-gray tone, smaller hollows with wormwood-mixed grass vegetation appear in a gray heterogeneous tone. The smallest hollows have a darkish-gray tone. Poorly anchored sand hills in all four zones are characterized by a light-gray tone. Identification of hollows with a thick plant cover and their differentiation by vegetation requires a combination of images in zones 3 and 4.

Psammophyte mixed grass and wormwood winter pastures in transplanted saline loosely anchored sand along the periphery of the dry channel (Fig. 5 d, 5). The photographs show ribbons with extremely broken edges stretching along the channel or at a sharp angle to it. The image is diffuse. The uniformity of semi-anchored sand is disturbed by the presence of individual hollows with a thick plant cover surrounded by sand hills. The predominating gray tone of the image in all 4 zones corresponds to psammophyte mixed grass-wormwood pastures. Elements of the image in darkish and dark-gray tones in the four zones correspond to abundantly-moistened depressions. Small light-gray and lightish-gray patches and strips in the 4 zones are sand hills. Small round darkish-gray and dark-gray spots in zones 1, 2 and 3 and lightish-gray spots in zone 4 are hollows with a thick plant cover. Boundaries of psammophyte-wormwood pastures with salt marshes in the river bed and with psammophyte mixed grass-brush pastures are distinct. Recognition of psammophyte mixed grass-wormwood pastures, determination of the structure of their surface,



establishment of the plant cover and the degree of surface moisture require images in zones 3 and 4.

Haymeadow lands. Xeromesophytic mixed grass-mesophytic cereal hay fields and meadows occupy medium-level flood land and higher channel faces, primarily on meadow alkaline alluvial soils briefly flooded with surface water and complex sandy-loam alluvium (Fig. 5 a, b, c, 6). Predominant mesophytic broadleaf cereals are: *Calamagrostis epigeios*, *Elytrigia repens*; xeromesophytic mixed grass: *Sephora allpecuroides*, *Mulgedium tataricum*, *Euphorbia gmelinii*, *Hieracium sect. umbellatae*, *Imila subsect britannicae*; hemixerophytic perennials: *Glycyrrhiza hirsuta*, *Onobrychis sp. sp.*; halomesophytic mixed grass: *Gypsophila perfoliata*, *Limonium gmelinii*. The projective canopy is 75-90%. At the time of the aerial survey most mesophytic cereals and mixed grasses had finished spring and early summer growth and were in a stage of summer dormancy and dryness. Depending on the ridge/hollow microrelief of the flood land, mixed grass-cereal haymeadows include, on one hand, fragments of meadow-bog soils with *Scirpus trigueter*, *S. tabernaemontani*, *Phragmites australis*, *Juncus gerardii*, *Carex acuta*, *Bolboschoenus maritimus*, *Calamagrostis nedini* and meadow "solonets" with *Aeluropus littoralis*, *Limonium gmelinii*, *Carex stenophylla*, *Suaeda linifolia*, *Artemisia santonica*, on the other.

Hay meadows stretch in continuous bands around oxbow lakes. In the lakes are long lighter narrow bands of flotsam. No flotsam is seen on photographs of haymeadows on well-drained shores of the oxbow channel. In zones 1 and 2 the mid-summer phytomass of vegetation has little effect on image tone, meadows are characterized by a gray heterogeneous tone analogous to pasture lands and differentiated by the presence of bands of flotsam. In zones 3 and 4 meadows are recognized by tone and by the presence of bands of flotsam. In zone 3 the meadow vegetation cover is characterized by a darkish-gray tone and in zone 4 by lightish-gray.

Mixed grass-cereal meadows along the oxbow channel were partially mowed. The mowed hay meadow is clearly differentiated in all zones not only by tone, but also by a sharp linear boundary and thick network of parallel bands corresponding to rolls of mowed hay. The light gray tone of the image of the hay meadow in zones 1, 2 and 3 corresponds to stubble and translucent soil. Mowed grass is distinguished by clear thin bands of a light gray tone. In zone 4 stubble appears darkish-gray with gray and lightish-gray moderately contrasting bands of mowed herbage. As yet unmowed hay meadows which are cut annually differ from stubble by a significant

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change in tone and clearly expressed heterogeneous image; a fine-spotted texture appears. In photographs in zones 1, 2 and 3 lands are characterized by fine-spotted texture and lightish-gray tone, and in zone 4 by gray. Xeromesophytic mixed grass-mesophytic cereal water meadows, not used for haying because access is barred by the oxbow channel, have the thickest herbage. In zones 1 and 4 they give a lightish-gray tone and in zones 2 and 3 — light-gray.

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Images of hay fields and meadows in zones 1, 2 and 3 show no basic differences in texture or tone, and only stubble is sharply distinguished against their background by a lighter tone due to the effect of translucent soil. In zone 4 the lightest, lightish-gray tone distinguishes the thickets unmowed meadows. A gray tone characterizes meadows cut annually but still uncut at the time of the aerial survey. Stubble and translucent soil are distinguished by a predominant darkish-gray tone. Differentiation of mixed grass-cereal hay fields by composition, structure of the plant cover and isolation of hay meadows against a background of pasture lands and thickets of meadow-bog vegetation require images in zones 3 and 4.

Thickets of meadow-bog vegetation (Fig. 5 a, b, c, 7), flooded with water throughout the entire summer, consist primarily of beds of *Phragmites australis* with up to 100% coverage. Thickets are about 2 m tall, the water 10-50 cm deep. During the aerial survey, reeds were in the earing stage, decoloration of the leaves had begun. The structure of meadow-bog vegetation is very mottled. In places where reed coverage is reduced to 60%, the surface of the water can be seen. In some places the abundance is increased and even other species form thickets — *Scirpus lacustris*, *Caltha palustris*, *Juncus compressus*, *J. articulatus*, *Typha foveolata*, *T. laxmaii*, *Cyperus difformis*, *C. badius*.

Thickets of meadow-bog vegetation occupy a large part of oxbow lakes. On photographs they are represented by a mosaic of uneven isometric or round patches with sharp moderately-contrasting or mosaic boundaries and less often by gradual transitions. In zones 1, 2 and 3 meadow-bog vegetation, regardless of the relief, is basically characterized by a darkish-gray tone, less often by dark-gray or gray. The structure of the plant cover is best transmitted in zone 2, particularly such phytocenotic characteristics as closeness and brightness. With reduction of closeness, the tone changes from gray to darkish-gray. Mosaic vegetation communities with complex indented structure produce distinct fine-spot texture on the image, while thick pure reed thickets are characterized by a more homogeneous tone.

Composition and structure of the plant cover is transmitted quite well in zone 4. The predominant tone of the image is lightish gray, it varies from light-gray to darkish-gray. The thickest pure reed thickets have the lightest tone. With reduction of the thickness of the plant cover, the tone changes to gray and darkish gray.

Reed thickets, practically pure, are characterized by a homogeneous light-gray or lightish-gray tone. Alternation of fragments of reed and horsetail communities is characterized by a lightish gray, less often by a gray heterogeneous tone. Fragments of bulrush, horsetail and rush communities have a gray or darkish-gray heterogeneous tone with fine-spot texture. Thin thickets give a homogeneous darkish-gray or dark-gray tone. Boundaries between vegetation and windows of water are most contrasting in zone 4. To find the distribution, structure and composition of shoreline vegetation it is necessary to use photographs in zones 2, 3 and 4.

River channel thickets of shoreline vegetation differ in composition from flood lands. Along both shores of the oxbow channel predominate *Phragmites australis*, *Salix sangaric*, *S. schrenkiana* and *S. wilhelmsiana* (Fig. 5b, 8). Narrow winding bands are distinguished on the photographs which repeat all the bends of the channel. In zones 1 and 2 they are characterized by a gray tone, in zone 3 by darkish-gray and dark-gray and in zone 4 by a lightish-gray or light gray homogeneous tone. Thick river channel osier-reed thickets are reliably distinguished by a combination of images in spectral bands 3 and 4.

Flotsam of dry residue of reeds, rushes, bulrushes and other plants is arranged in bands among the thickets of shoreline vegetation and along the shores of oxbow lakes (Fig. 5 a, b, c, 9). In flood meadows along the shores of oxbow lakes it appears as narrow interrupted bands, paralleling each other along the shore line. Among thickets in oxbow lakes flotsam forms chains of narrow short strips, often oriented parallel to the shore. In all four zones of the survey it appears lightish-gray, less often gray. However, on the surface of lakes and in water meadows flotsam shows greatest contrasts with growing vegetation in zone 3 and is practically undifferentiated in zone 4.

Trash salt marshes on the accumulative plain along the shores of oxbow lakes, in the bottoms of large depressions, in dry river channels and in isolated hollows in Tosyn-Kum sand dunes (Fig. 5 a, c, d, 10). There is practically no plant cover

in trash salt marshes. Flood land of halophytic semibrush stretches along the periphery of salt marshes. From the point of view of agricultural land use, these lands are unusable. Configuration and dimensions of the images of salt marshes are extremely varied and are determined by the difficult relief in which they are formed. Along the northwest shore of the oxbow lake salt marshes, basically dry, less often wet, stretch in a narrow twisting band which changes on the northern shore to a chain of separate round salt marshes. The large dry trash salt marsh in the lake depression has an oval shape and polygonal surface structure. Dry, moist and wet trash salt marshes stretch in a broad winding strip in the dry channel. Dry and wet round or oval salt marshes are located in isolated small depressions among sandy hills.

In zones 1, 2 and 3 areas and boundaries of salt marshes are accurately identified by a light-gray or lightish-gray tone and diffuse spotty picture. Both dry and moist salt marshes in these spectral bands are expressed by a light-gray tone and not differentiated. Wet salt marshes are distinguished by a lightish-gray heterogeneous tone, sometimes changing to gray. In zone 2, which transmits the structure of the surface quite well, the polygonal surface structure of the large trash salt marsh can be recognized. Pictures in zone 4 make it possible to discriminate dry, moist and wet salt marshes by tone and when necessary, a large number of gradations of the surface moisture content of trash salt marshes. Dry salt marshes are characterized by a lightish-gray heterogeneous tone, moist salt marshes by a gray heterogeneous tone and wet ones by a darkish-gray heterogeneous tone, changing to dark gray. A combinations of zones 2 and 4 can be used to identify salt marshes, reveal the polygonal structure of the surface if it exists and differentiate dry, moist and wet salt marshes.

The water surface is represented in small "windows" among thickets in oxbow lakes, in the oxbow channel and in a small pond on the western slope of the Turgay hollow (Fig. 5 a, b, c, 11). Typical of the photograph of open water is a darkening of tone and increase of contrast with the surrounding vegetation communities in zone 4. Water surfaces which are comparatively uniform in turbidity and degree of silting of the bottom are characterized by a homogeneous gray, darkish-gray tone in zones 1, 2 and 3 and by a dark tone in zone 4. An increase of turbidity changes the tone in zones 1, 2 and 3 to lightish-gray but does not affect the tone in zone 4. Identification of the extent of open water surfaces, accurate definition of their boundaries, the depth of reservoirs and turbidity of the water require a com-

ination of zones 2 and 4.

Settled areas are represented by one small farmstead on the western slope of the Turgay hollow. On the photograph it is expressed by a group of individually oriented rectangles corresponding to structures, separated by narrow light bands of streets (Fig. 5 a, 12). The tone of the rectangles varies from lightish-gray to darkish-gray. The bands separating them are gray in all zones. Contrasts increase from zone 1 to 3. In zone 4 settled lands are much less differentiated. /71

Dirt roads (Fig. 5 a, b, c, 13) on photographs are expressed primarily by light lines. The tone depends on the composition and moisture of soils. Dirt roads on the surface of the oxbow lake in fresh and moderately moist meadow soils are distinguished in zones 1, 2 and 3 by a light-gray tone and in zone 4 by a gray, darkish-gray tone. Dry dirt roads usually have a lightish-gray tone in all zones. The contrast of roads against a background of the surrounding meadow vegetation increases from zone 1 to 3. In zone 4 dirt roads are poorly differentiated.

To approach an objective characterization of optic contrasts of natural formations on multiband photographs, we compared density characteristics of individual natural formations on densitometric profiles, at identical points, on four zonal negative images in blue-green, green-yellow, orange-red and red-infrared zones 1, 2, 3 and 4. (Fig. 6 a, b). Densitometry was carried out in a microphotometer with relative aperture of 2 mm, which corresponds on the negative to 0.1 mm and on site to 24.5 m. Registrograms of the density of negatives are integrated to exclude random topographic discrepancies in identifying densitometric measurements. In view of the absence of sensitometric control of photography, direct comparison of the densities of zonal photographs was impossible as photography conditions were not standardized. However, for solving our problem — determining relative ratios of image densities of basic natural formations on zonal images — it was sufficient to compare relative densities. The maximum density contrast in an identical profile on each zonal image was taken as 1. Such relative density values were used repeatedly in relative densitometric comparisons.

On images in the blue-green spectral band (zone 1), maximum densities ( $D = 1.0$ ) are typical of dry trash salt marshes. High density values on the negative are also assigned to moist salt meadows ( $D = 0.7-0.9$ ) and stubble ( $D = 0.8-1.0$ ). Uncut hay meadows are well differentiated from stubble by medium density ( $D = 0.6-$

0.7). Such densities of the negative are typical of xerophytic vegetation. River channel reed-willow thickets and turbid water have almost the same densities ( $D = 0.5$ ). Meadow-bog vegetation is distinguished by lower values ( $D = 0.2-0.5$ ). Minimum densities on the negative are given by thin thickets of meadow-bog vegetation ( $D = 0.0-0.1$ ) and the transparent water surface ( $D = 0.0$ ).

In the green-yellow spectral band (zone 2) maximum density is given by dry and fresh salt marshes ( $D = 1.0$ ). In this spectral interval stubble also has high densities ( $D = 0.9-1.0$ ), uncut meadows slightly lower ( $D = 0.8-0.9$ ). Such density values are observed in xerophytic pastures. River channel thickets have medium densities ( $D$  about 0.6). Meadow-bog vegetation is characterized by lower densities: from ( $D = 0.4-0.6$ ) for pure reed thickets to ( $D = 0.1-0.3$ ) for rush, sedge and other communities. The density of the image of turbid water is low ( $D = 0.4$ ). Least densities of the negative image are given by thin thickets of meadow-bog vegetation ( $D = 0.0-0.2$ ) and the transparent water surface ( $D = 0.0$ ).

In the orange-red spectral band (zone 3) maximum densities are presented by dry and fresh salt marshes ( $D = 1.0$ ). Moist salt marshes and xerophytic pastures have similar density on the negative ( $D = 0.9$ ). Uncut hay fields have slightly lower density ( $D = 0.8$ ). The main mass of meadow-bog vegetation is characterized by values of ( $D = 0.5-0.8$ ). Thin thickets have slightly lower densities ( $D = 0.2-0.3$ ). Minimum densities on the negative image are given by the transparent water surface ( $D = 0.0$ ).

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In the far red-near-infrared spectral band (zone 4) the highest density values on the negative are given by dry salt marshes ( $D = 1.0$ ) and pure reed thickets ( $D = 0.9-1.0$ ). Meadows and uncut hay are practically undistinguishable from reed thickets and give densities of ( $D = 0.9$ ). Reed thickets in combination with sedge, rush, etc., are characterized by lower density ( $D = 0.8$ ). Thickets of meadow-bog vegetation without reeds are distinguished by values of ( $D = 0.7$ ). Dead and dried thickets give densities of ( $D = 0.6$ ). Stubble has a density of ( $D = 0.6-0.7$ ). Thin meadow-bog vegetation is characterized by a density of ( $D = 0.1-0.5$ ). The lowest values are given by the water surface ( $D = 0.0$ ).

Analysis of densitometric characteristics of photographs and visual estimates of tone in the four zones of the survey showed that images of objects in zones 1, 2 and 3 in blue-green, green-yellow, orange-red rays have no significant differ-

ences. Only a slight increase of contrasts is observed with an increase of wavelength. Because of the high ratio of light diffusion in blue rays and low spectral contrasts of natural formations, images in zone 1 ( $\lambda = 0.44-0.54$  micron) are characterized by the lowest photographic tonal contrasts of individual elements. Contrasts increase sharply in zone 2 ( $\lambda = 0.52-0.59$  micron) in the green-yellow rays and reach a maximum in zone 3 ( $\lambda = 0.59-0.69$ ) in orange-red rays.

The structure of thick plant cover is traced in greatest detail in zone 2. The clearest differentiation between sections of thick mesophytic plant cover and a surface with thin and xerophytic vegetation is observed in zone 3. Typical of surveying in these zones is the most detailed transmission of the structure of thin plant cover, complexity of soils and character of the bottom surface due to the maximum spectral contrast between relatively low ratios of spectral brightness of thick-growing vegetation and relatively high ratios of water surface, thin and dry vegetation. In zone 4 ( $\lambda = 0.67-0.73$  micron) two opposite tendencies are traced in changes of spectral brightness of vegetation and background. At  $\lambda$  up to 0.70 micron, growing vegetation has ratios of spectral brightness 3-4 times lower than the soil background and typical of  $\lambda$  over 0.70-0.72 micron is a sharp increase in the reflection of light by green plants and reduction of that by water and wet surfaces. In this zone a sharp delimitation is also observed between the water surface and dry land, salt marshes with various surface moisture.

According to the change in tone of the positive image in the four zones, all isolated objects are combined into three groups (Fig. 7 a, b, c, d).

I. Objects having an identical image tone in all zones. Contrasts increase from zone 1 to zone 3 and drop sharply in zone 4 (Fig. 7 a, b, c, 1). These are moderately and poorly productive pasture lands, including wormwood-xerophytic cereal pastures along the western side and slope of the Turgay hollow and on the alluvial plain on alkaline light chestnut and brown soils and "solonets," psammophyte mixed grass-wormwood pastures in the Tosyn-Kum sand dune on the accumulative plain on loosely anchored saline sand, poorly productive wormwood-saltbush pastures of "solonets" and succulent saltbursh of "solonchak" soils, bands of dry flotsam along the shores of oxbow lakes and on their surface, settled areas and dirt roads.

II. Objects characterized by sharp darkening of tone of the positive image in zone 3 in relation to zones 1 and 2 and lightening in zone 4 (Fig. 7 a, b, c, d, 2). These are wormwood-psammophyte mixed grass-shrub pasture lands in the Tosyn-Kum sandy desert in hollows and large depressions of the relief, highly productive haymeadows, represented by mixed grass-couch grass haymeadows on flood lands, highly productive thickets of shoreline vegetation on oxbow lakes in meadow-bog soils.

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III. Objects giving a darkening of tone from zone 1 to zone 4 with contrasts increasing in this direction (Fig. 7 a, b, c, d, 3). These are water surfaces in the channel of the oxbow and on oxbow lakes, moist and wet salt marshes along the shores of oxbow lakes and on the bottom of the dry channel, abundantly moistened lowlands, stubble with the translucent surface of meadow soil, in mowed flood meadows. However, with high turbidity, lightening of the tone of the water surface is observed in zone 3 in relation to zones 1 and 2 and sharp darkening in zone 4.

Comparison of visual estimates of tone and densitometric characteristics of the image of studied objects in these four zones showed that there is no need to use all four zones to obtain maximum information and a combination of two or three is sufficient (Fig. 8 a, b, c, d).

Objects not giving basic differences in image tone in the four studied spectral bands can be distinguished by one zone best transmitting the structure of thin plant cover, soil complexity and character of bottom surface, i.e. zone 3 (Fig. 8 a, b, c, d, 1). However, to monitor plant cover and surface water content it is necessary to compare images in zones 3 and 4.

Mesophytic and hygromesophytic plant communities with a large projecting canopy (over 70-80%) and large phytomass (over 10-20 centners/hectare), which give sharp darkening of the positive tone in zone 3 in relation to zones 1 and 2 and lightening in zone 4, are identified by comparing their tones in zones 3 and 4. For a special study of the surface structure of phytocenosis, besides these zones, an image in zone 2 is required (Fig. 8a, b, c, d, 2).

For identifying water objects and differentiating salt marshes with different surface moisture, for which increased darkening of the positive image from zone 1 to zone 4 is typical, a combination of zones 2 and 4 is required (Fig. 8 a, b, c,



d, 3).

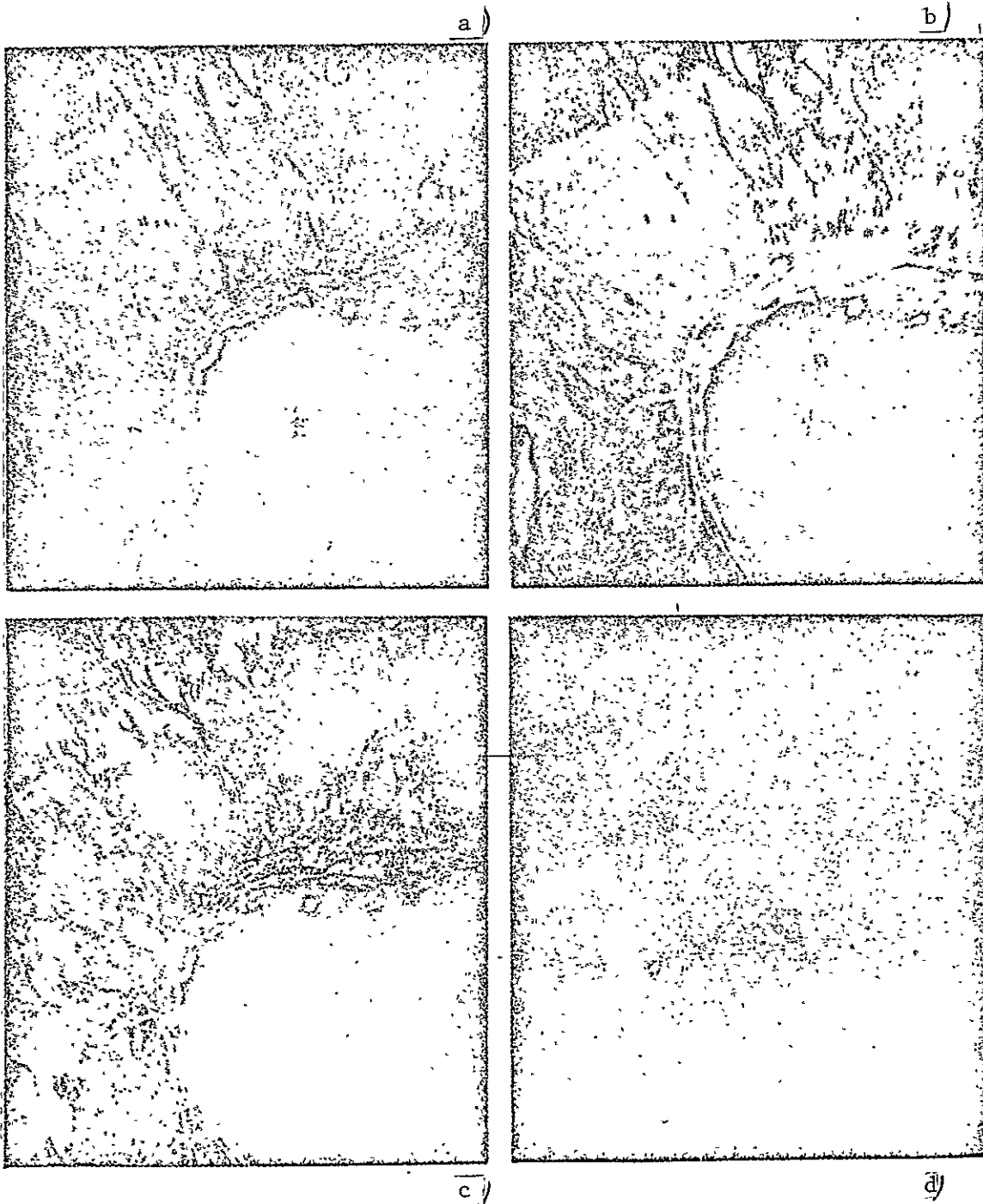
We found no additional information from the image in zone 1 in analyzing test objects on the plain and in the absence of cloud shadows. However, judging from literature data, use of an image in zone 1 is necessary to identify agricultural lands when there is the factor of depth distribution of relief on darkened slopes or in sections darkened by clouds.

Results of visual-instrumental analysis of multiband aerial photographs of the Turgay key section showed that reliable identification of agricultural lands in the semi-desert zone when the relief is a poorly broken plain in the absence of clouds is provided by photography in three spectral bands: 2 ( $\lambda\lambda = 0.52-0.59$  micron), 3 ( $\lambda\lambda = 0.59-0.69$  micron) and 4 ( $\lambda\lambda = 0.67-0.73$  micron). The data presented verify a number of well-known recommendations for selecting optimum spectral bands for multiband photography of vegetation and agricultural lands (1, 3, 4):  $\lambda\lambda = 0.44-0.48$  micron,  $\lambda\lambda = 0.52-0.56$  micron,  $\lambda\lambda = 0.62-0.68$  micron,  $\lambda\lambda = 0.72-0.82$  micron.

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Figure 1. Set of multiband aerial photographs. Wavelength ranges: a.  $\lambda\lambda = 0.44-0.54$  micron; b.  $\lambda\lambda = 0.52-0.59$  micron; c.  $\lambda\lambda = 0.59-0.69$ ; d.  $\lambda\lambda = 0.67-0.73$  micron

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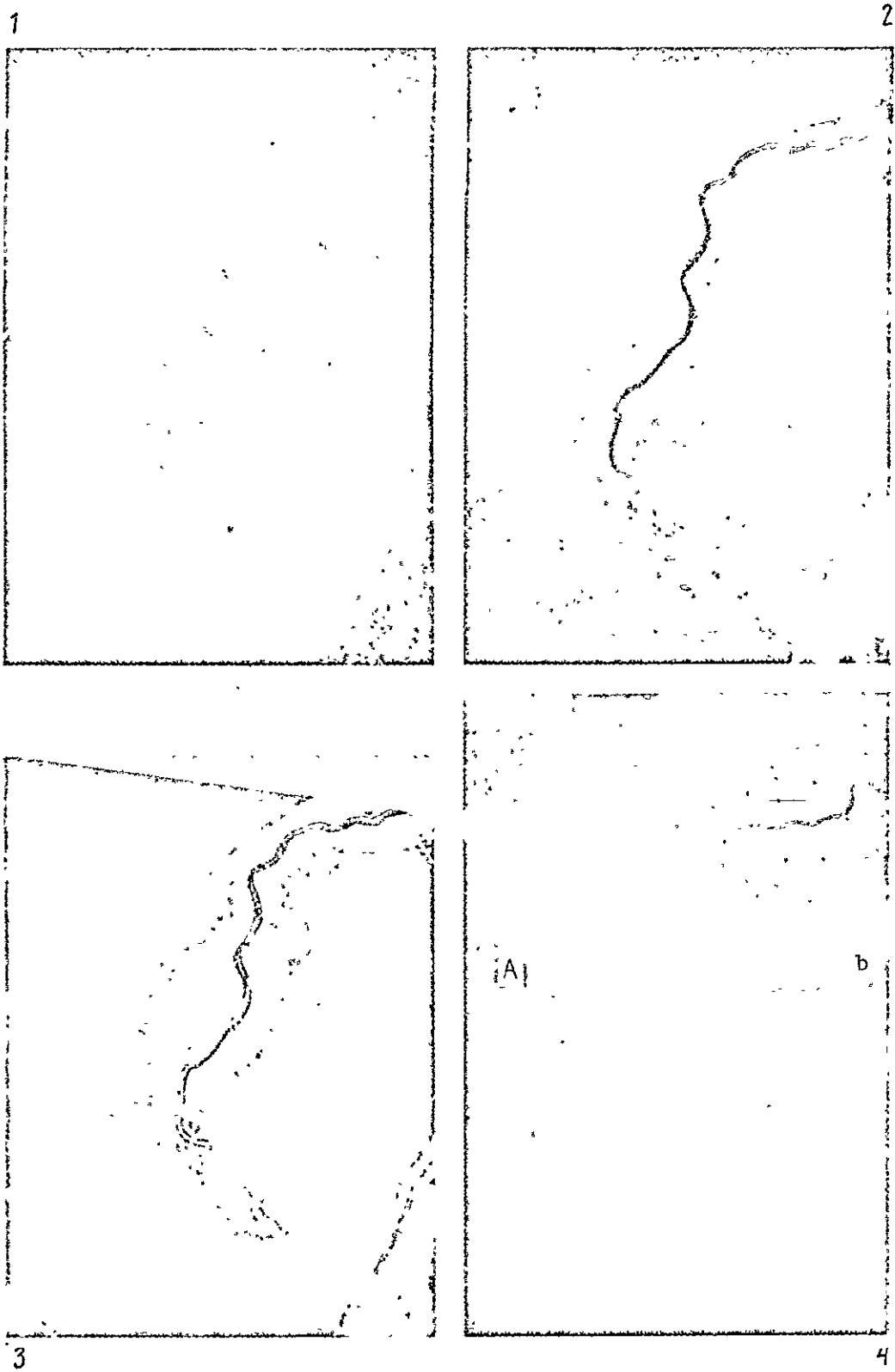
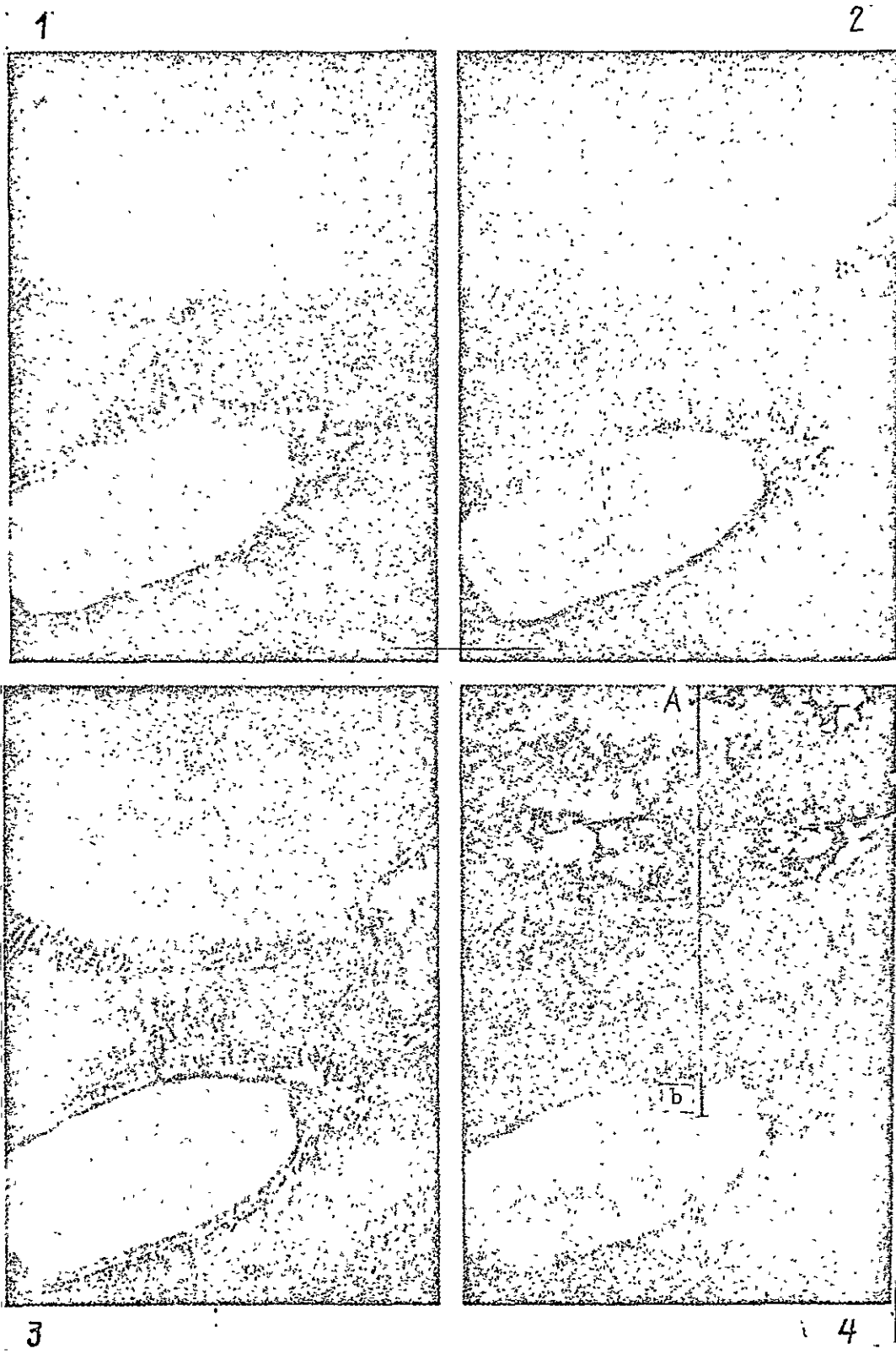


Figure 2. Set of multiband aerial photographs. Wavelength ranges the same.



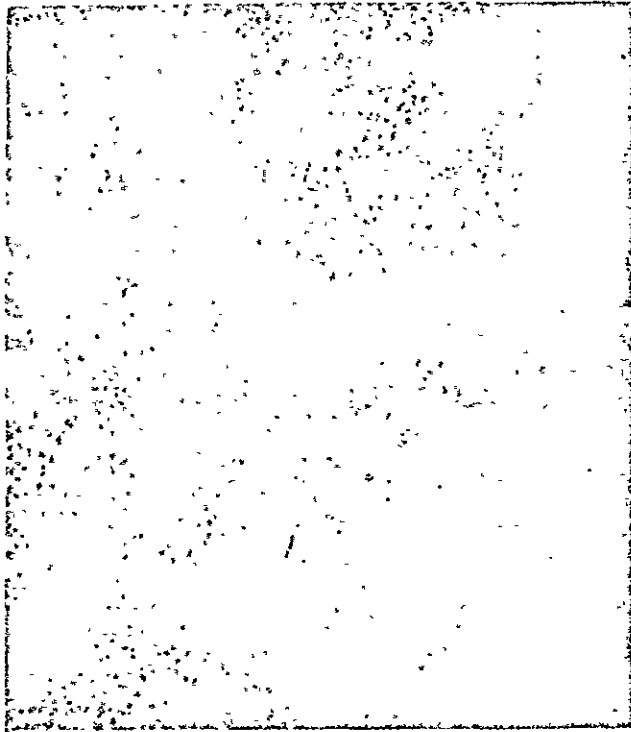
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Figure.3. Set of multiband aerial photographs. Wavelength ranges the same.

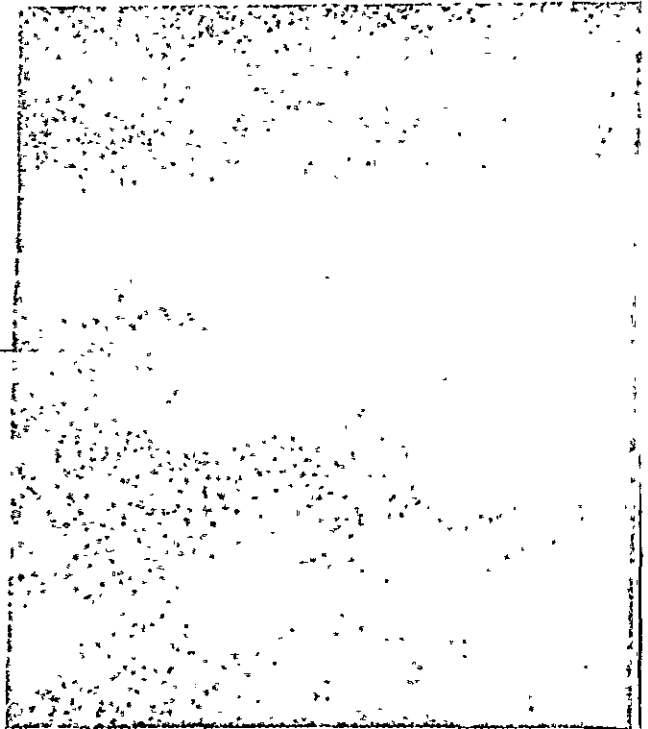
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Figure 4. Set of multiband aerial photographs. Wavelength ranges the same.

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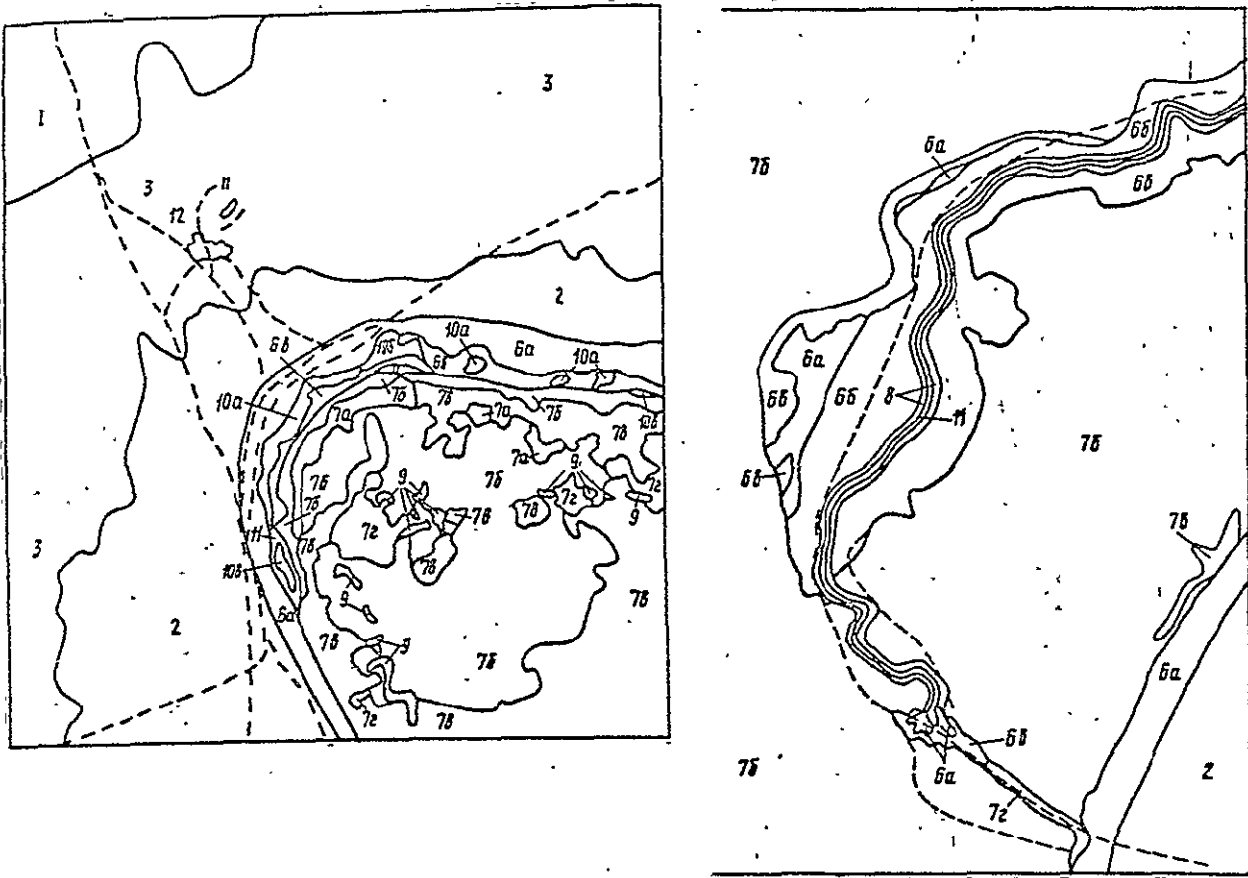


Figure 5 a, b. Outline maps of the identification of pasture and haymeadow lands of test sections of the Turgay hollow by multiband aerial photographs (a - Fig. 1, b - Fig. 2, c - Fig. 3, d - Fig. 4). Legend: 1. Wormwood-xerophytic cereal spring and fall pastures on brown alkaline soils in a complex with "solonets." 2. Wormwood and associated plant year-round pastures in light chestnut sandy alkaline soils in a complex with "solonets." 3. Wormwood-saltbush and succulent saltbush fall pastures on "solonets," saline "solonets" and "solonchak" soils. 4. Wormwood-psammophytic mixed grass-brush pastures on light chestnut sandy soils. A) in small hollows, B) in large depressions. 5. Psammophytic mixed grass-wormwood winter pastures on weakly anchored sand. A) in dry channel, B) in abundantly moist lowland. 6. Xeromesophytic mixed grass-mesophytic cereal hay fields and meadows on meadow alkaline soils. A) uncut, B) mowed, C) not yet mowed. 7. Thickets of meadow-bog vegetation on meadow-bog alkaline soils. A) pure reed thickets, B) reed and horsetail thickets, C) rush, bulrush, sedge communities, D) thin thickets of meadow-bog vegetation. 8. Riverchannel osier-reed thickets on alluvial sands. 9. Flotsam of dry residue of reed, sedge, bulrush and other plants among thickets of shoreline vegetation and along shores of oxbow lakes, 10. Trash salt marshes practically devoid of vegetation with a border of halophytic semibrush along the periphery. 11. open water surface. 12. settled lands. 13. - - - dirt roads. 14. — boundaries of agricultural lands. 15. — boundaries of plant and soil sections within tracts having different density values in four zones.

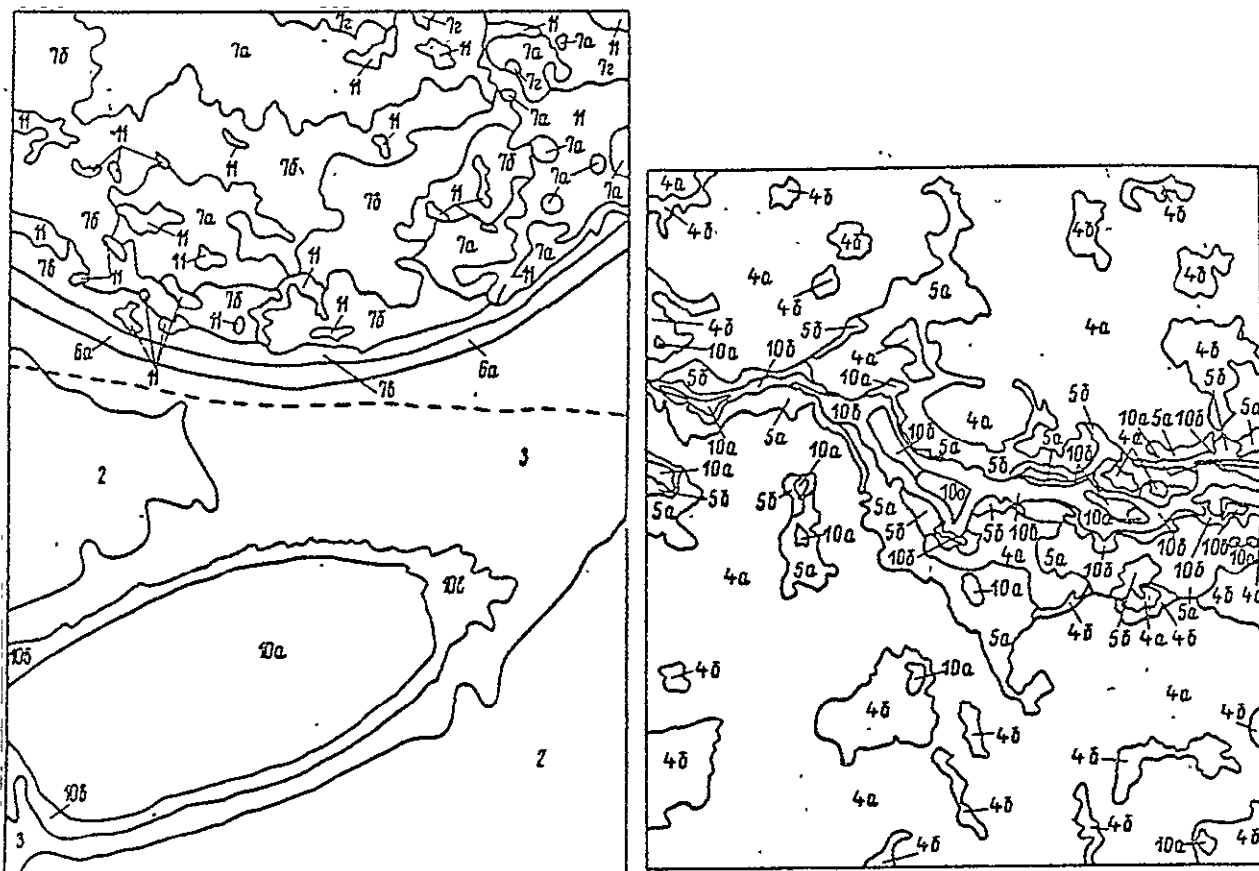


Figure 5, c, d. Outline maps of identification of pasture and haymeadows of test sections of Turgay hollow on multiband aerial photographs (a — Fig. 1, b — Fig. 2, c — Fig. 3, d — Fig. 4). Legend: 1. Wormwood-xerophytic cereal spring and fall pastures on brown alkaline soils in a complex with "solonets." 2. Wormwood and associated plant year-round pastures on light chestnut sandy alkaline soils in a complex with "solonets." 3. Wormwood-saltbush and succulent saltbush fall pastures on "solonets," saline "solonets" and "solonchak" soils. 4. Wormwood-psammophytic mixed grass-brush pastures on light chestnut sandy soils. A) in small hollows, B) in large depressions. 5. Psammophytic-mixed grass-wormwood winter pastures on poorly-anchored sands. A) in dry channel, B) in abundantly moist low lands. 6. Xeromesophytic mixed grass-mesophytic cereal hay fields and meadows on meadow alkaline soils. A) uncut, B) mowed, B) not yet mowed. 7. Thickets of meadow-bog vegetation in meadow-bog alkaline soils: A) pure reed thickets, B) reeds and horsetail thickets, B) rushes, bulrush, sedge communities, Γ) thin thickets of meadow-bog vegetation. 8. River channel osier-reed thickets on alluvial sands. 9. Flotsam of dry residue of reed, sedge, bulrush and other plants among thickets of shoreline vegetation and along the shores of oxbow lakes. 10. Trash salt marshes practically devoid of vegetation with a border of halophytic semibrush along the periphery: A) dry, B) moist, B) wet(11) open water surface. 12. Settled lands. 13 - - - dirt roads. 14. Boundaries of agricultural lands. 15. Boundaries of plant and soil sections in tracts having different density values in four zones.

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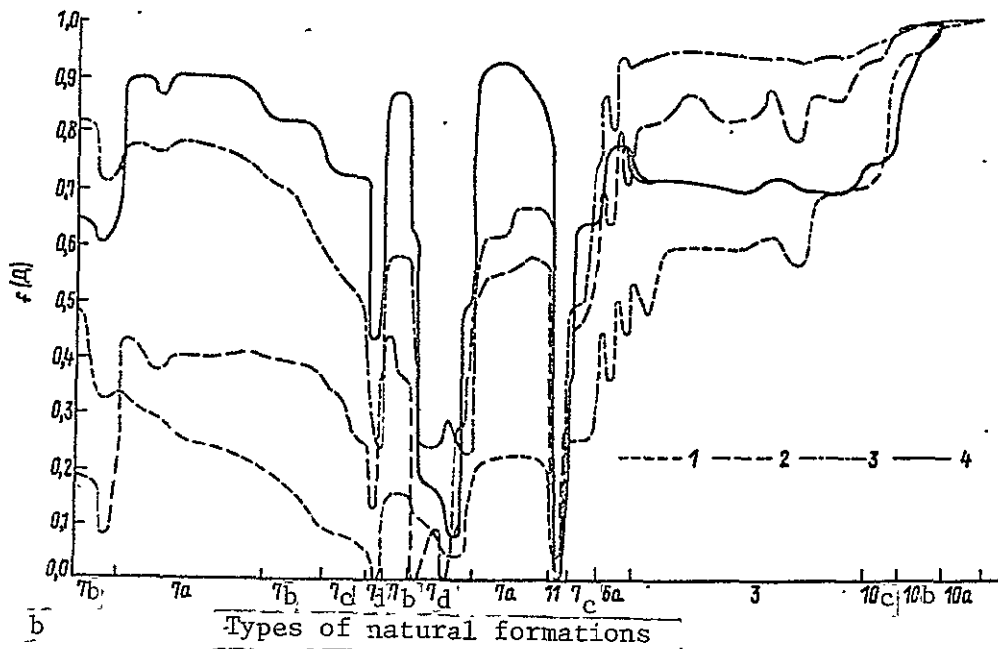
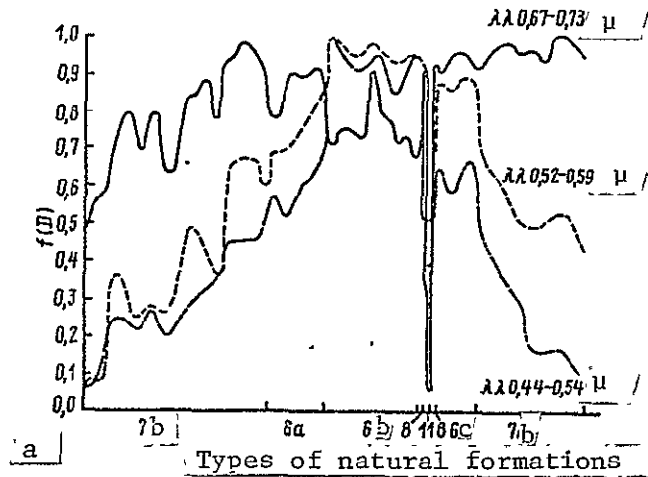


Figure 6. Generalized densitometric profiles of multi-zonal photographs in photoactinic zones. 1.  $\lambda\lambda = 0.44-0.54$  micron, 2.  $\lambda\lambda = 0.52, 0.59$  micron, 3.  $\lambda\lambda = 0.59-0.69$  micron, 4.  $\lambda\lambda = 0.67-0.73$  micron, reduced to one density contrast (6a latitudinal profile through Figure 2; 6b - meridional profile through Figure 3.) Types of natural formations (see legend to Figure 5.)

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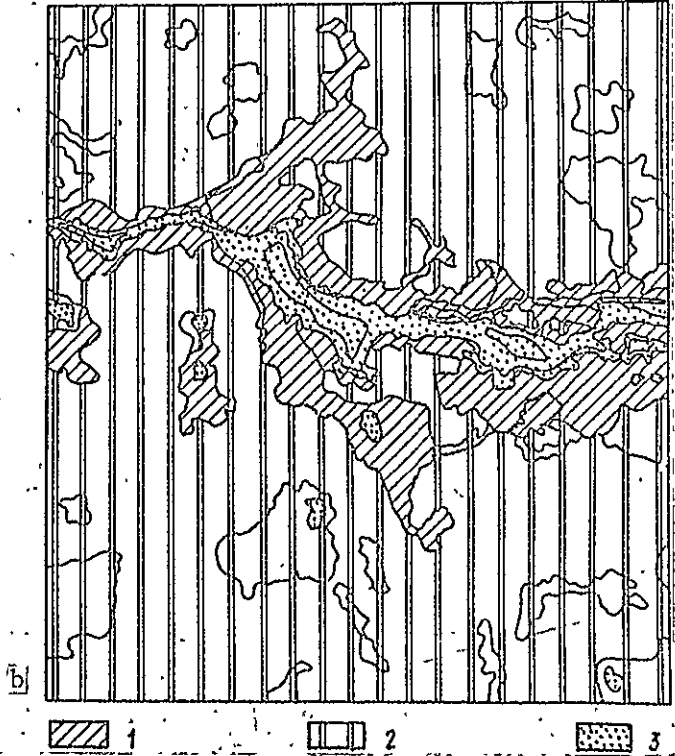
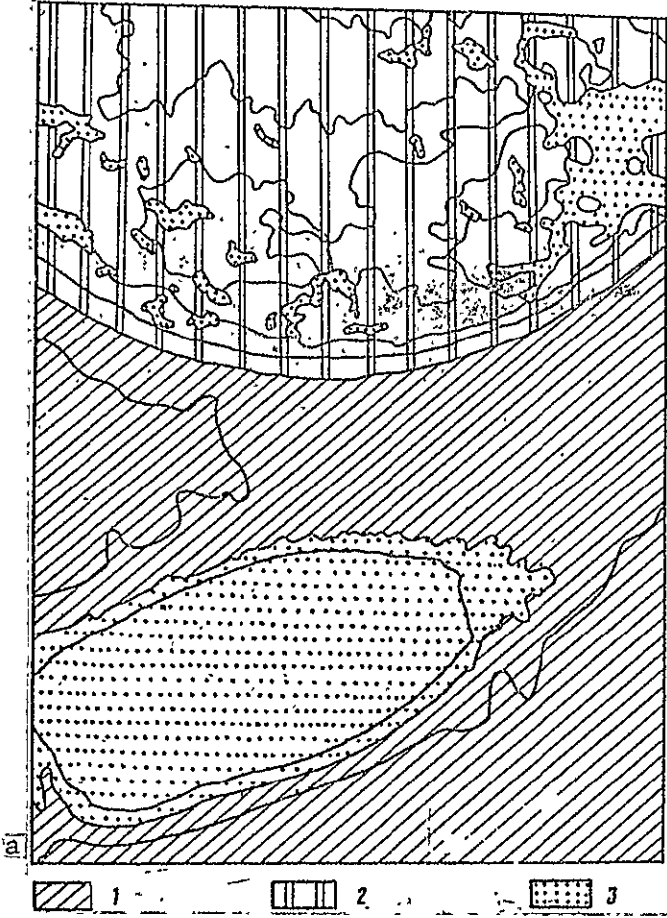


Figure 7. a, b

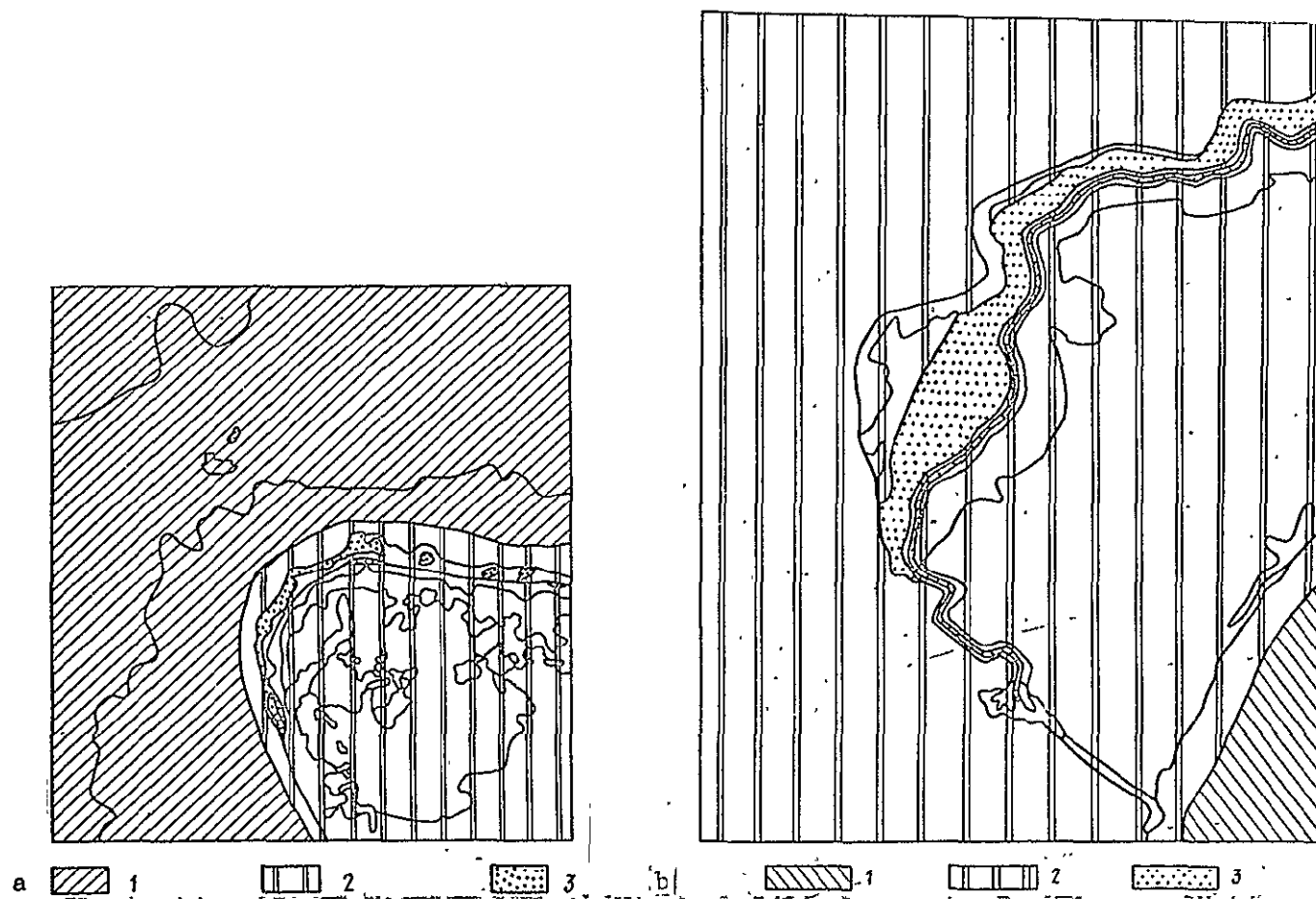


Figure 7. Distribution of tone values of positive image in four zones of aerial photography (a - Fig. 1; b - Fig. 2; c - Fig. 3, d - Fig. 4). Legend: 1) image tone in four zones of survey relatively stable; 2) image tone darkens in zone 3 in relation to zones 1 and 2 and lightens sharply in zone 4. 3) image tone gradually darkens from zone 1 to zone 4.

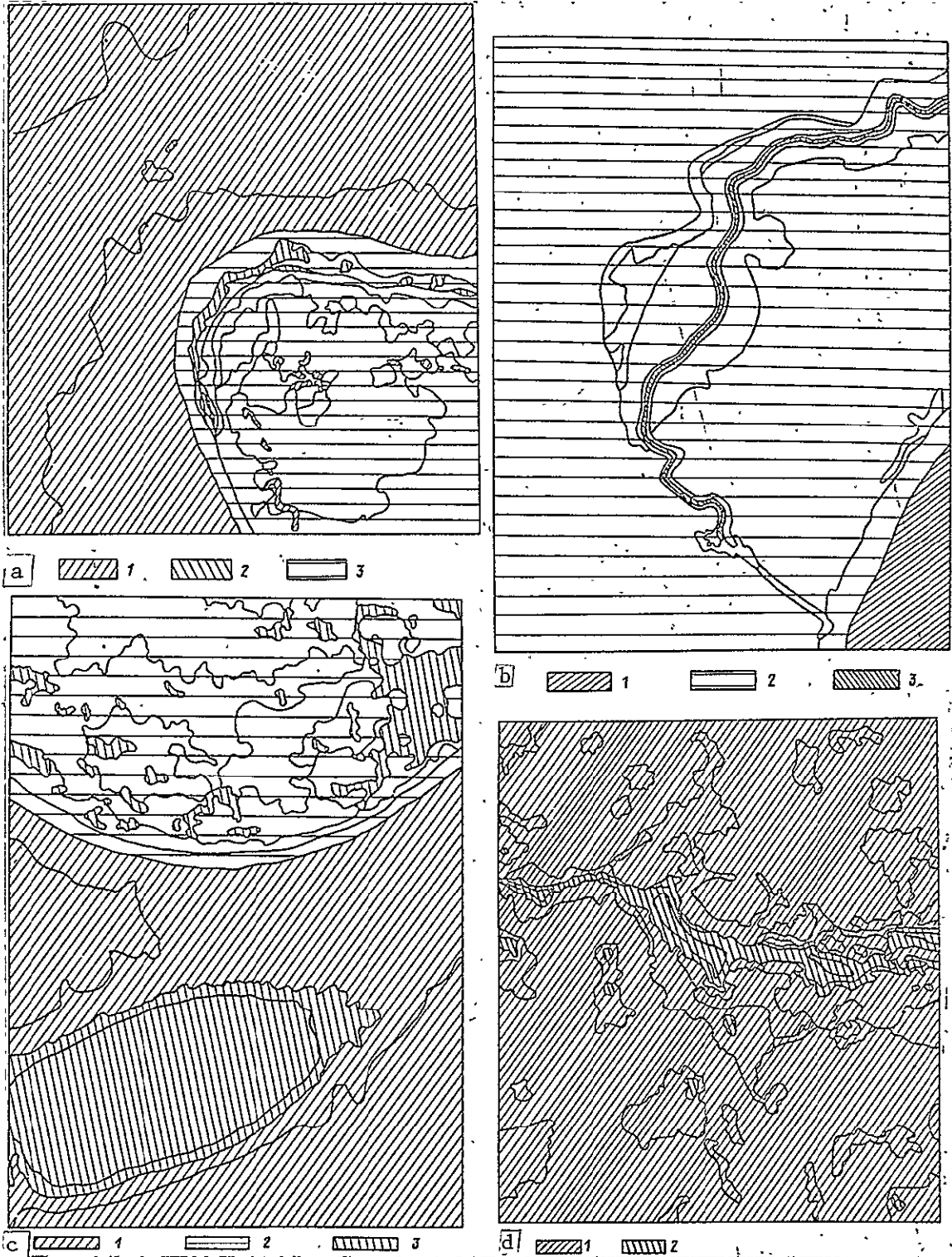


Figure 8. Optimum combinations of spectral intervals of multiband aerial photography of pasture and haymeadow lands in Turgay hollow (a - Fig. 1, b - Fig. 2, c - Fig. 3, d - Fig. 4). Legend; 1) combination of zones 3 and 4, 2) combination of zones 2 and 4, 3) combination of zones 2, 3 and 4.

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Part II. S. M. Aleksandrov, V. L. Andronikov, S. Yu. Antonova, D. S. Asoyan, I. S. Garelik, Ye. V. Glushko, M. Ye. Gorodetskaya, T. A. Markova, I. A. Nikolayev, M. G. Sinitsyna, N. V. Fadeyeva and G. A. Shershukova

The Comparative Informativeness of Multizonal Photographs in the Study of the Relief and Landscapes of Semidesert and Dry Desert: A Case Study of the Turgay Site

I. S. Garelik, M. Ye. Gorodetskaya, A. Ye. Kozlova, N. V. Fadeyeva

Geomorphological studies were begun at the Turgay site in 1973, and in 1974 comprehensive geomorphological, geobotanical and landscape studies related to investigation of the informative properties of multizonal aerial photographs. A study of the information content of the latter is necessary at the first stage of developing a technique for interpreting them in order to solve specific geographical problems whose subject matter at the Turgay site determines its agricultural value and the scientific topic of the research.\*

The Turgay site is located in West Kazakhstan in the southern half of the Kustanayskaya and greater part of the Turgayskaya oblasts of the Kazakh SSR. It is situated within the gently-stepped plains of the Turgay trough and is characterized by a change in natural zones from the steppe, moderate-arid in the north, arid and dry in the center to semiarid in the south. In the northern steppe region are concentrated lands which were plowed only in the 1950's and which are mainly used for grain crops, while in the southern, semiarid region animal grazing dominates (Natural Zoning of Northern Kazakhstan, 1960).

In the geomorphological studies\*\* in the dry steppe and semidesert an analysis was made of the information content of multizonal photographs to study the nature and degree of erosion and erosion-denudation breakup of the relief of watersheds, slopes, near-slope denudation plain-pediments. In the landscape and geobotanical\*\*\*

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\* Scientific leader of the work of IGAN (Institute of Geography of the Academy of Sciences, USSR) at the Turgay site--Cand. Geog. Sci. M. Ye. Gorodetskaya.

\*\* Geomorphological studies made by Cand. Geog. Sci. M. Ye. Gorodetskaya and A. Ye. Kozlova.

\*\*\* Landscape studies made by Cand. Geog. Sci. N. V. Fadeyeva.

\*\*\*\* Geobotanical studies made by co-worker of BIN AN (V. L. Komarov Botanical Institute of Academy of Sciences) Cand. Bot. Sci. I. T. Fedorova.  
[Translator's note: Site of this reference omitted in original text.]

research in the semidesert the information content of multizonal photographs was studied in order to interpret, on the one hand, the nature-territorial complexes of the "natural boundary" type, and on the other hand, the plant associations. All the work was conducted on key sections. Each section was exhausted by all the specialists both under field and laboratory conditions from the viewpoint of solving the given geographical problems.

Theodolite profiles were set up on the key sections and were then used to evaluate the information content of the multizonal aerial photographs. Under field conditions, in the course of the theodolite profile, the relief, soils, vegetation and landscapes were studied and described in detail; visual field interpretation was made of the aerial photographs from the key sections. Under laboratory conditions interpretation and subsequent photometry were conducted in order to obtain the qualitative-quantitative indices characterizing the optical properties of the targets isolated on the profiles. Summary tables were compiled for each key section in the range of the given theodolite profile according to the results of the field investigation, interpretation and primary photometric processing of the negatives. These tables gave the summary characteristics of the interpreted elements of the relief, vegetation and landscapes and also information on the maximum, minimum and mean values for the optical densities of the image ( $D_{max}$ ,  $D_{min}$ ,  $D_{me}$ ) of the given natural targets. These and other quantitative characteristics were obtained by measuring the optical densities of the negatives on a  $G_{11}$  microphotometer with a  $G_{11}B_1$  standard compensating recorder. Measurements were made along the lines corresponding to the theodolite profiles. The width of the instrument diaphragm was 0.2 mm which corresponded approximately to 10 m at the site. The statistical characteristics were computed according to the well-known methods (Afanas'yev, 1970; Physical Fundamentals, 1967; Yanutsh, 1963, et al).

Unfortunately there were no data of sensitometric control of aerial photographs, nor data on the transmission of light filters and the distribution of illumination on the field of view of the aerial cameras which made it difficult to compare the characteristics of optical density of the image of the same targets in different zones. Nevertheless, the task of evaluating the comparative information content can be satisfactorily met even without these data. The complete studies showed that the development conditions and nonuniformity of exposure in the focal plane did not have a significant effect on the assessment of comparative information content of the multizonal photographs. We explain the latter by the closeness of the indicated conditions for all the photographs of one series.

The aerial photographs taken in different spectral zones both in the summer and fall were given the same procedural treatment. Photometric measurements were made on the negatives of aerial photographs of close scales while the visual analysis was made on photographs enlarged three times.

In the dry steppes the summer photography took place in the zones: 500-560 nm, 520-590 nm, 590-690 nm, 670-730 nm. In the semidesert, in the zones: 500-560 nm, 520-590 nm, 670-730 nm and on September 13, 1973 in the zones: 500-560 nm, 540-620 nm, 590-690 nm and 630-740 nm.

In the semidesert, the field investigation, qualitative interpretation of aerial photographs and comprehensive profiling were conducted on nine key sections, of them on six--according to the materials of fall multizonal photography. In the dry steppes it was according to the material of summer photography on five sections.

The task of studying the relief, in particular, the nature and degree of its erosion-denudation breakup, according to materials of aerial and space photographs is of practical importance since these characteristics to a significant degree determine the economic importance of the land resources in the range of the water dividing plains, the slopes limiting them and the near-slope plains (pediments).

According to the indices of erosion-denudation breakup of the surface, four main morphological types of relief of varying economic value were separated.

The first type is unbroken and lightly broken up water dividing plains and gently sloping inclines. This type is characterized by closed, round nano- and microsinks of an undermining-sagging origin on the planar, top surfaces and linearly-oriented along the microstretch and microsink on the gently sloping inclines. Here in the dry steppe are concentrated the main areas of plowed fields, while in the semidesert there are grazing and hay fields.

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The second type is broken up and denuded sections of slopes and near-slope denudation plains - pediments. This type of relief is characterized by linearly-oriented erosion-denudation microbeds, microwashouts, microravines and extensions. Developed sloping surfaces, formed on the basic tertiary deposits dominate on the sections of area denudation and drift (young pediments). In an economic respect this is primarily unproductive land.





The third type is large negative elements in the relief: in the semiarid zone-- watershed hollows with clear traces of moistening which sharply distinguishes them from the two previous types of relief, and in the dry steppes--valleys of small rivers and large troughs.

The fourth type is an ash relief of sandy areas both anchored by vegetation and loose.

The first two types of relief are basic for the watershed plains of the dry steppes and semidesert. They are characterized by specific groups of natural boundaries of the semiarid and dry-steppe landscape.

In the semidesert on the interfluvial area south of the valley of the River Uluzhilanshik, within the unbroken and lightly broken up watershed plain with the ancient erosion-denudation ridge-hollow relief are dispersed natural complexes of the southern semidesert which have a complex morphological structure. Here are isolated: 1--natural boundaries of unbroken ridge summits composed of sandy loam, sand, light loams with pronounced heterogeneity of the soil and vegetation covers governed by undermining-sagging forms of the microrelief of the nanosink type. These natural boundaries are characterized by combinations of three facies. 2-- natural boundaries of lightly broken up ridge inclines composed of sandy loam and light loams with a clear heterogeneity of soil and vegetation covers governed by a complex network of linearly-oriented stretches and nanosinks. These boundaries are characterized by combinations of three, seldom, two facies. 3--natural boundaries of planar and slightly sloping inter-ridge hollows composed of sandy loams and light loams with less pronounced heterogeneity of the soil and vegetation covers. These natural boundaries are characterized by combinations of two, less often, three facies. 4--natural boundaries of basins composed of sandy loams, average and heavy loams with pronounced heterogeneity of the soil and vegetation covers governed by differences in the saline and water patterns. These natural boundaries are characterized most often by combinations of two facies.

Natural complexes of the northern semidesert are characteristic for the flat-topped monadnock, slightly domed watershed plains of the Tobolo-Ul'koyak interfluvial area which are similar in nature and degree of breakup. Here are represented: 1-- natural boundaries of unbroken summits and slightly inclined plains composed of sands, underlying light loams with weakly marked heterogeneity of soil and vegetation covers. They are characterized by combinations of one, less often two facies.

2--natural boundaries of strongly broken up and denudation inclines composed of sandy loams, underlying light loams and clays with pronounced heterogeneity of the soil and vegetation covers governed by linearly-oriented stretches and small hollows. They are characterized by combinations of two-four facies. 3--natural boundaries of watershed hollows composed of sandy loams, underlying light loams and clays with clearly marked heterogeneity of soil and vegetation covers governed by differences in moistening and salinization of the soils. They are characterized by combinations of two-four facies.

As for the sandy areas of the semidesert, in the case of the southern edge of the sand deserts of Akkum we separate: 1--ridge-barkhan relief made of anchored and semi-anchored sands; 2--inter-ridge depressions composed of sands and sandy loams anchored by vegetation and 3--loose sands. /88

In the dry-steppe agricultural subzone, the unbroken and slightly broken up plains of the water divides and their slopes are almost continuously plowed. On the aerial photographs, on the background of plantings in the range of the watershed plains systems of linear micro-extensions and microhollows are traced. The smallest erosion grooves which are visually undetected under field conditions are converted into linearly-oriented microdepressions in the lower section of the decline. Within the plowed watershed plain sections are found on which the bed-rock shines through-- in this case the soil cover is most often almost completely washed off.

The broken up and denuded plains of slopes and pediments, usually not tillable, here have a network of troughs, gullies, washouts and hollows determining the considerable depth and density of their linear erosion-denudation breakup. The troughs, gullies, washouts and upper sections of the pediments are generally devoid of any plant cover. Relatively high turf cover here only characterizes the shallow hollows and stretches.

The valleys of small rivers with temporary catchment areas are separated by meadow-mixed grass vegetation which in the summer is characteristic for moistened sections of the dry river bed, while the trough bottoms are separated by an abundance of saline soil and secondary erosion cuts.

The interpretation signs of the relief and natural-territorial complexes of the landscapes are the structure of the photo image and the phototone. The structure of the photo image is mainly determined by the features of the microrelief which is

identified on the photographs by the change in vegetation. The phototone is determined by the composition and distribution over the elements of the relief of the plant communities which indicate the facial differences of the landscapes.

In the semidesert the unbroken surfaces of the watersheds are interpreted in the zone 590-690 nm according to the characteristic spotty-diffusion structure of the photo image which is governed by the presence of closed nano- and microsinks, while the lightly broken up surfaces of the watershed slopes, due to the appearance of linearly-oriented microstretches and microsinks--according to the spotty-linear and spotty-banded structure of the photo image. At the same time, the white phototone is characteristic for the black wormwood and black wormwood-Anabasis vegetation of the alkali soil microsinks and microdepressions; the grey--for the white wormwood-fescue-tyrsik vegetation of the unbroken sections of watersheds and their slopes with brown and light-chestnut alkaline soils; light grey for the meadow grass-white wormwood vegetation of the watersheds, slopes and terraced levels of basins with brown and light-chestnut alkaline soils, less often desert alkali soils.

Strongly broken up surfaces of slopes are characterized by spotty-linear or linear ("striated") structure, and the near-slope plains - pediments by coarse spotty and linear-spotty structure of the photo image. The white phototone corresponds here either to sections completely devoid of vegetation, sometimes saline, or to black wormwood and Anabasis plant groups on alkali soil deserts; the light grey is typical for Anabasis-kokpechnik vegetation on alkali soil deserts, and the grey for wormwood-grassy vegetation on light-chestnut soils within the sections preserved from breakup.

The photo images of the bottoms of watershed basins are primarily spotty, less often, spotty-linear banded. The phototone of the images is white, grey and dark grey, nearly black. The first of them is determined by the spread of black wormwood-Anabasis vegetation on the alkali soil deserts, and the last by the presence of meadow vegetation on the meadow-saline soil.

Sandy areas are characterized by a spotty structure of the photo image and frequent alternation of light grey and dark grey phototones which is governed by the alternation of inter-ridge depressions anchored with vegetation and barkhans often with semibare slopes and summits. The sections of shifting sand are characterized by a uniform, light grey phototone.

In the dry steppe, the images from photography in the same zone for unbroken and lightly broken up surfaces of watersheds and slopes with microsinks and micro-stretches have spotty-diffusion and diffusion-banded structure; intensively broken up and denuded slopes and pediments--spotty-linear and fine-spotty-cellular figures. The valleys of small rivers and troughs are characterized by linear and linear-spotty structure of the photo image. The white phototone on the photographs is typical for saline soils in the halophytic vegetation; light grey phototone indicates the sections eroded with exposed bed-rock; grey characterizes the wormwood-grassy steppes; dark grey--grassy-mixed grass steppes and the darkest--hygrophilous vegetation, "islands" of pine forest and bushes. Areas occupied by grain crops have a relatively dark phototone which in the given case we explain by the time of the photography (the month of June). For barley crops a relatively darker tone in comparison with perennial grasses is characteristic.

Visual analysis of the multizonal photographs showed that the contours of the same natural targets can be visually interpreted on photographs in all the zones we examined. The differences in the images of the same targets in different zones are traced to the different degree of contrast and the average density. Therefore, in speaking further about a better information content in a certain zone we will have in mind the greater facility and reliability of the visual interpretation of certain targets on the photographs in the given zone.

We will illustrate the technique of instrumental processing of the photographs in a specific example. The aerial photograph (fig. 1) and the schematic diagram of interpretation (fig. 2) show the placement of the theodolite profile. Photometry of the negatives in all zones occurred according to this profile. Sections corresponding to the different natural targets (in the given case--different types of relief) were determined on the registrograms. For each such section the average amounts of optical densities of the image were computed and used to construct graphs (fig. 3). These graphs present a graphic picture of what targets are best isolated among the others in a certain zone. Thus, in zones 500-560 nm and 520-590 nm the watershed plain is clearly separated from the slope and pediment limiting it. Photographs in zones 500-560 nm and 670-730 nm in contrast to the photographs in the zone 520-590 nm make it possible to positively distinguish the unbroken regions and those with slight erosion-denudation microbreakup ( $IV_1$ ) from the regions of intensive erosion-denudation microbreakup. At the same time on the photograph in the zone 520-590 nm the sections of pure water ( $VIII_1$ ) and bogs ( $VIII_2$ ) are more clearly differentiated.

For the characteristics of the information content of the photograph both in separating the individual targets of interpretation and in interpreting the photograph on the whole the differences were computed for the average optical densities of the contacting portions ( $D_{me_{11}} - D_{me_1}$ ) which characterize the image contrasts of mixed targets (table 1 for fig. 2).

In order to assess the information content of the photograph in order to solve specific geographical problems a comparison was made of the differences in mean values of optical densities characterizing the given specific targets of the natural environment. In the overall evaluation of the information content of the photograph a criterion, in the first approximation, may be the mean zonal amount of differences in the mean values of the optical densities of the image.

In the examined case, these amounts are practically the same for all zones (0.08; 0.08; 0.09), which confirms the conclusion made during visual interpretation that on the whole no zone should be given preference. However, if the zones are selected from the viewpoint of the best solution of the specific task--detection of 1/90 the broken up and denuded lands which are unproductive in an economic sense--then the zone 520-590nm should belong to the most informative.

In the study of the comparative information content of the zones, in a number of cases criteria were calculated and then were employed such as the average amount of entropy and criteria based on computation of the average statistical characteristics for the values of optical densities.

In the landscape studies the primary attention was focused on investigation of the facial combinations and the differences within the natural boundaries. In this respect, primary importance is attached to the amounts characterizing the maximum and minimum values for the optical densities since the mean values do not reflect the internal differences in the landscape sections. Therefore, the study of the information content of photographs in order to investigate the facial differences used the following indices: the scope of values for the optical densities of the images within each landscape portion ( $D_{max.} - D_{min.}$ ) and the difference in the maximum ( $D_{2max.} - D_{1max.}$ ) and minimum ( $D_{2min.} - D_{1min.}$ ) values for the optical densities of the images of two contacting portions. These indices permit an evaluation of the degree of facial differences, while those photographs which make this evaluation easier and more reliable are more informative for solving the landscape tasks.

TABLE 1 FOR FIG. 2

No of contacting elements in relief (names in key to fig. 2)	Difference in mean values for optical densities of images according to zones		
	500-560	520-590	670-730
I - II	0,22	0,26	-
II - III	0,03	0,04	0,04
III - IV	0,01	0,03	0,03
IV - VI	0,04	0,07	0,21
IV - VII	0,08	0,12	0,19
VII - VIII	0,26	0,32	0,42
I <sub>1</sub> - I <sub>2</sub>	0,12	0,14	-
I <sub>2</sub> - II <sub>1</sub>	0,17	0,16	0,01
II <sub>1</sub> - II <sub>2</sub>	0,00	0,02	0,07
II <sub>2</sub> - III <sub>1</sub>	0,04	0,02	0,01
III <sub>1</sub> - III <sub>2</sub>	0,01	0,02	0,06
III <sub>2</sub> - III <sub>3</sub>	0,03	0,01	0,06
III <sub>3</sub> - IV <sub>1</sub>	0,13	0,06	0,04
IV <sub>1</sub> - IV <sub>2</sub>	0,06	0,00	0,10
IV <sub>2</sub> - IV <sub>3</sub>	0,01	0,02	0,05
IV <sub>3</sub> - VI <sub>1</sub>	0,03	0,02	0,12
VI <sub>1</sub> - VI <sub>2</sub>	0,07	0,09	0,01
Average for zone	0,08	0,08	0,09

[Translator's note: All commas in numerals are to be replaced with periods.]

The results of an evaluation of the comparative information content of the photographs of various zones for solution of geomorphological and landscape problems are presented in tables 2 and 3. /93

For the geomorphological studies in interpreting the types of relief of varying economic importance (table 2), the information content of photographs in different zones changes depending on the task, region and season. Thus, a photograph in the zone 590-690 nm is the best for interpreting the relief in the semidesert in fall, but in the dry steppe in summer. And the 520-590 nm zone is the best for photographing the relief of the semidesert in the summer.

For landscape studies in the semidesert (table 3) generally the most informative are the zones 590-690 nm, 630-740 nm and only for the natural boundaries of the

TABLE 2

COMPARATIVE INFORMATIVENESS OF THE MULTIZONAL PHOTOGRAPHS IN INTERPRETING THE TYPES OF RELIEF  
OF VARYING ECONOMIC IMPORTANCE

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Natural zones subzones	Major elements of relief	No.	Types of relief and their economic use	Most informative zones for isolating separate natural targets		Most informative zones for studying the natural region as a whole	
				summer	fall	summer	fall
Steppe dry steppe	Watersheds, slopes near-slope plains	1	Unbroken and lightly broken up plains of watersheds and their slopes. Plowed fields	520-590			
		2	Broken up and denuded plains of slopes and pediments. Unproductive lands, pasture land	520-590 590-690		520-590 590-690	
	Negative elements relief-region of seasonal flooding	3	Valleys of small rivers and trough bottoms. Hay fields, pasture land	500-560 520-590			
Semidesert	Watersheds, slopes near-slope plains	1	Unbroken and lightly broken up plains of watersheds and their slopes. Pasture land, hay fields		540-620 590-690		
		2	Broken up and denuded plains of slopes and pediments. Unproductive lands	590-560 520-590	540-620 590-690		
	Negative elements of relief. Region of seasonal flood	3	Lake with lake flood- plain. Bottom of water- shed basin	520-590 670-730	540-620 630-740	500-560 520-590	590-690 540-620
	Sandy areas	4	Ridge-fine-barkhan relief semi-anchored and anchored with vegetation		540-620 590-690		
		5	Loose, shifting sands		590-690		

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TABLE 3

## INFORMATIVENESS OF MULTIZONAL PHOTOGRAPH OF SEMIDESERT LANDSCAPES FOR VARIOUS TYPES OF ECONOMIC USE

Types of landscape and their economic use		Groups of natural boundaries	Structure (pattern of photo image)	Most informative zones	
Type	Subtype			for different subtypes	for all subtypes of semidesert
1	2	3	4	5	6
Semidesert	<u>Northern subtype</u> Pasture land for all types of cattle, hay fields,	Natural boundaries of watersheds and unbroken upper parts of slopes	Uniform, not clearly marked, spotty	590-690 nm 630-740 nm	590-690 540-620 630-740
	Pasture land, unproductive for ec. use lands	Natural boundary of slopes	Linear-striated, round-spotty	540-620 nm 500-560 nm	
	Pasture land, hay fields, unproductive lands	Natural boundary of hollows and depressions	Round-spotty	540-620 nm 500-560 nm	
	<u>Southern subtype</u> Pasture land primarily for sheep	Natural boundary of watersheds and unbroken upper sections of slopes	Clear spotty-diffusion or diffusion-spotty	590-690 nm 630-740 nm	
	Pasture land mainly for sheep	Natural boundary of slopes	Spotty-linear-diffusion, linear-banded	590-690 nm 630-740 nm	
	Pasture land mainly for sheep, rarely hay fields	Natural boundary of hollows and depressions	Uniform	590-690 nm 630-740 nm 540-620 nm	
	Hay fields, pasture land	Natural boundaries of basins (macro-sinks)	Uniform, diffusion-spotty, linear-spotty-banded	630-740 nm 590-690 nm 540-620 nm	

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strongly broken up slopes and hollows of the northern subtype of the semidesert zone 540-630 nm, 500-560 nm. The optimal selection for the semidesert is: 590-690 and 540-620 nm.

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Thus, the studies made in the Institute of Geography showed that for dry steppes and semidesert the majority of geomorphological and landscape tasks, including such national economic ones as studying the degree and nature of the breakup of tillable and pasture lands, can be solved with the materials of aerial photographs taken in two spectral zones whose selection is determined in each case by the region of photography, the season and the specific assigned task.

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Fig. 1. Aerial Photograph

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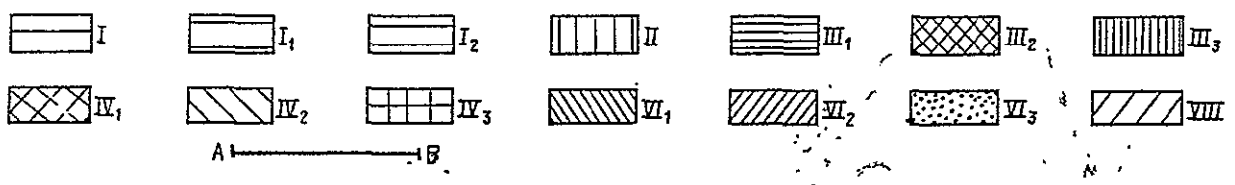
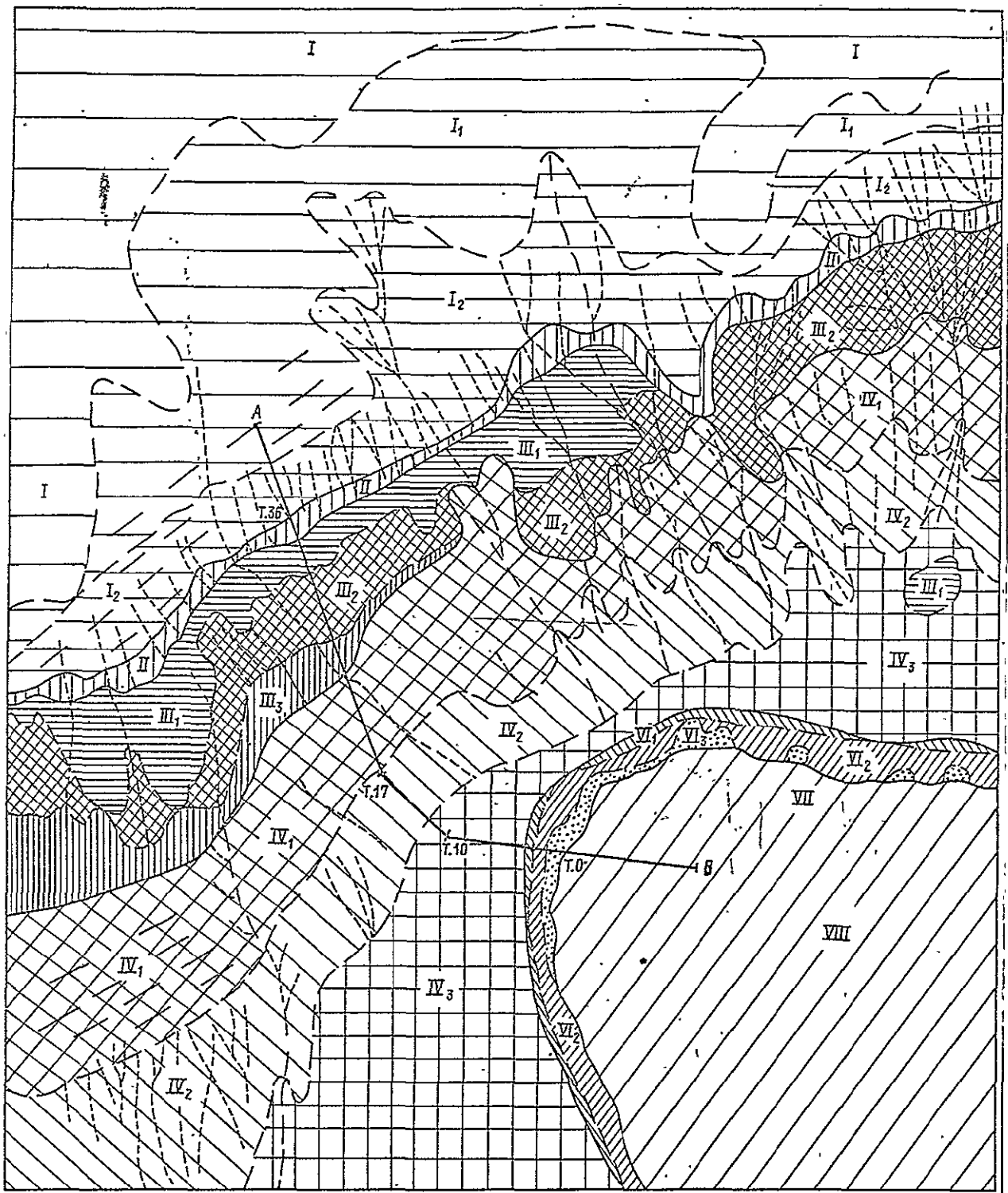


Fig. 2

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Fig. 2. Schematic diagram of geomorphological interpretation of aerial photograph of western edge of the Turgay hollow. Region of formation of near-slope denudation plains-pediments and of contraction by denudation of the watershed area (northern semi-desert of southern Turgay). Compiled by M. Ye. Gorodetskaya.

1--Watershed (over 125 m abs.); I--monadnock-hilly plain--region of erosion and denudation; I<sub>2</sub>--inclined near-slope plain--region of area drift; I<sub>3</sub>--inclined near-slope plain--region of debris cone and linear breakup. II--Steep slope (118-125 m abs.). III--Young pediment (110-118 m abs.); III<sub>1</sub>--slightly inclined plain of slope foot--region of area denudation and drift; III<sub>2</sub>--slightly inclined plain--region of denudation and slight erosion-denudation microbreakup; III<sub>3</sub>--gently sloping plain--region of erosion-denudation linear breakup. IV--Old pediment (87-110 m abs.); IV<sub>1</sub>--slightly inclined plain--region of denudation and slight erosion microbreakup; IV<sub>2</sub>--gently sloping plain--region of intensive erosion-denudation breakup; IV<sub>3</sub>--gently sloping plain--region of intensive linear erosion breakup; VI--Lake floodplain: VI<sub>1</sub>--high seasonal level of standing water; VI<sub>2</sub>--low floodplain. VII--transition from dry land to water. VIII--lake overgrown with thick, hygrophilous vegetation with windows of water. A-B--Theodolite profile.

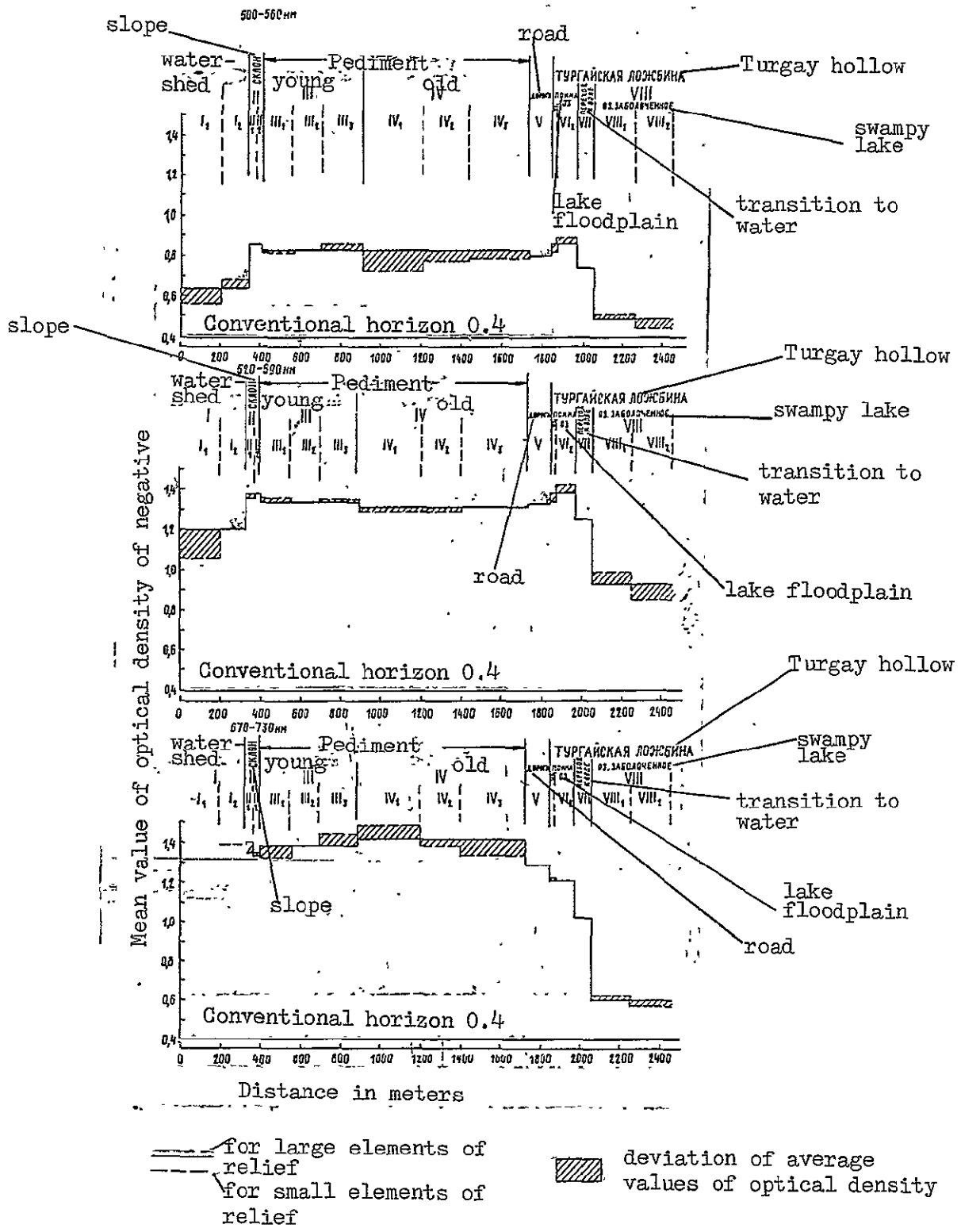


Fig. 3. Graphs of average optical density of images of different natural targets along the theodolite profile A-B. Compiled by M. Ye. Gorodetskaya.

[Translator's note: All commas in numerals are to be replaced by periods.]

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The Use of Photographs from the Resource Satellite ERTS for Landscape Mapping and Analysis of the Landscape Dynamics

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V. A. Nikolayev, V. I. Kravtsova and T. A. Markova

Studies of natural resources by space devices are currently characterized by the appearance of satellites especially designed for this purpose. They include the American resource satellite ERTS launched in 1972. The specifications of the satellite and the photographs taken from it have been treated in the literature many times. We recall only that they were obtained by scanning in four spectral ranges. The system of processing the satellite data envisages transformation of the image into a projection of the international world map m. 1:1,000,000. The resolution of the photographs (size of minimum details of site reflected on the photograph) is 70-100 m. The solar-synchronous orbit of the satellite makes it possible to photograph any territory under the same lighting conditions, ensures practically complete survey of the earth's surface for 18 days and makes it possible to repeat the photography 20 times during the year.

Many works treat the use of photographs from the ERTS satellite on the territory of the USA and other foreign countries. It has become traditional to study the photographs for geological purposes. It is observed that they permit reconstruction of the total picture of disruptive disorders in the earth's crust, of which only 10-15% were previously mapped [12]. Correlations are analogous for the previously interpreted and mapped elements and for other components of the natural environment, for example, in relation to vegetation. Thus, according to the photographs of the Seward peninsula 17 types of vegetation were successfully isolated instead of the four types shown on earlier maps [4].

The use of photographs from the ERTS satellite in the region of agricultural studies is directed towards developing methods of operative mapping of the condition of plantings to predict the yield and to detect regions of plant diseases. Regional models are developed for predicting the productivity of pasture land [6] and forests, the decrease in pasture lands, soil erosion, forest and grass fires are detected [4].

A great effect is produced by photographs from ERTS to detect pollution of the natural environment, primarily, water pollution [8]. According to the photographs from this satellite, for example, a recording was made of water disposal by industrial enterprises on the sea coast near New York and in Lake Champlain, where, based on the image of the scum currents the state authorities took judicial action

against the paper-making plant that contaminated the reservoir [10].

Work is being conducted to study pollution of the water storage basins in Kansas [16]. An attempt was made to investigate the coastal waters of the Gulf of Mexico in order to evaluate the fish resources [14], which however, showed the great complexity of this problem.

The perspective for using photographs from ERTS in snow hydrology is important--they can be used to evaluate the areas of melting snow (according to photographs made in different zones) which is extremely important for hydrological predictions. In the study of sea ice the photographs permit mapping with sufficient detail of the ice borders in m. 1:250,000, while the use of zonal images ensures the necessary information on the types of ice [5]. One can name a number of important regional works, the study of geology and hydrology of desert regions of Atacama (Chili) [15], subarctic and arctic regions of Alaska and Iceland [13], and others.

All of these studies, which were made in the first months of operation of the ERTS satellite, are of a preliminary nature, but the majority of them present a very optimistic evaluation of the perspectives for using photographs from this satellite.

It is natural that the ERTS photographs are used for updating maps--for example, they are used to detect a change in the shape of the Bandar-Shakh peninsula due to a reduction in the level of the Caspian Sea [9], to find new islands in the Amazon delta [9] and to raise the question of creating topical maps m. 1:1,000,000 according to photographs from this satellite [11]. The answer to this question requires serious methodical work on using space photographs in topical mapping which, unfortunately have not been given the proper attention. Only preparatory works can be named which are directed towards ensuring the creation of structural and metallogenetic maps for South America. In this respect, 12 key sections were selected in the Andies and Brazilian Shield which were provided by ERTS pictures and which were studied by scientists from Argentina, Bolivia, Brazil and Columbia in order to establish a single approach to their analysis and the development of a unified technique for working with the photographs [7].

It is apparent from the aforementioned that among the majority of studies on the ERTS photographs there are comparatively few examples of the valuable cartographic use of these photographs. Meanwhile, they cover a considerable area of territory and the use of these photographs to compile topical maps is of great importance.

There are photographs from the ERTS satellite also for the territory of the Soviet Union. We used one of these photographs encompassing the region of Northern Balkhash and the western part of Lake Balkhash which was kindly presented to us by the representative of NASA, Mr. Jaffey during the Soviet-American meeting to study the natural environment by space resources in 1973.

Landscape analysis of the photograph and its cartographic treatment were implemented jointly with the co-workers of the laboratory of aerial photography methods in the department of geodesy and cartography and the department of physical geography of the USSR in the Geography Department of Moscow University.

The photograph we analyzed encompasses the territory roughly between  $45^{\circ}$  and  $47^{\circ}$  n.l. and  $72^{\circ}$  and  $75^{\circ}$  e.l. It was taken on September 10, 1972. A color print was used with distorted color reproduction obtained as a result of synthesis of the image in three zones: 0.5-0.6, 0.6-0.7, 0.8-1.1  $\mu\text{m}$ . The photograph was not precision treated in which a correspondence is reached for the map image on the scale of 1:1,000,000 with accuracy  $\pm 100\text{m}$ . It was obtained at the stage of general processing, therefore there is a discrepancy observed in the position of identical points on the map and photograph (to 2-3 mm along the edges of the photograph); we therefore had to verify the position of the interpreted contours with the larger-scale survey-topographical maps.

In so far as on the space photographs the entire complex of components in the natural environment is reflected, the most complete use of the information contained in them is achieved by landscape interpretation. We therefore decided to research the possibility of using photographs from the ERTS satellite primarily for landscape mapping, especially as there are absolutely no examples of this use in the foreign literature. On the other hand, a study of the photograph as material for creating a landscape map to a great extent predetermines its evaluation from the viewpoint of specialized topical mapping, in so far as the contours and content of the landscape map are partially repeated on the specialized topical maps.

Laboratory interpretation of the space photograph was preceded by flight line-key field studies during which both individual components of the natural complexes (geological structure, relief, soils, vegetation) and the morphological structure of the landscapes as a whole were investigated. Simultaneously with this, the interpretation signs of different types of landscapes on the space photographs were detected at the site. This made it possible to conduct continuous laboratory

interpretation on the entire area of the photograph.

The interpreted contours were drawn on black and white reproductions enlarged to a scale of 1:300,000 from the original photograph but the interpretation constantly used the color photograph which facilitated the work to a considerable extent.

The process of laboratory interpretation included several stages. At first, all the contours were separated on the photograph which differed in color, tone and /100 representation of the image. Then these contours were "saturated" with the landscape contents.

Interpretation and subsequent typology of the landscapes and their space images were implemented on the basis of an interdependent analysis of the field landscape observations and the space photograph in comparison with the data of specialized topical and topographical maps.

Landscape interpretation of the space photographs synthesized in conventional colors on the desert territory is characterized by definite specificity. The zonal-desert landscapes and intrazonal-meadow and swamps have a very drastic color division. Further recognition of the natural complexes within the desert type with separation of the genus and species of landscapes primarily rests on an analysis of the shades, tonality and texture of the space photograph, as well as the configuration and territorial associations of the landscape contours.

Under conditions of exceptional thinness of the desert vegetation cover whose projective covering does not exceed 30%, the geological structure and soil cover of the territory recognized on the photographs directly play an especial landscape-indicating role.

Our experience showed that the space image of desert landscapes on the arid-denudation foundation plains and mountain-cone-shaped hill areas primarily gives an idea about their geological structure. In virtue of the intensively occurring denudation the soils and friable covers are poorly developed here. Through them one can clearly read the rocky base of the landscape. Lithologic and structural-geological originality of the landscapes determines the morphological peculiarities of their relief, and subsequently the intralandscape differentiation on the elementary natural complexes. According to the litho-edaphic indices it is possible to interpret the vegetation cover inherent to each type of landscapes.

In the transition to the accumulative surfaces presented in the studied region by alluvial terraces and bottoms of ancient valleys the main indicating role in the landscape interpretation transfers to the desert soils. The structure of the rocky foundation of the valleys-grabens is masked by the sedimentary cover and comparatively completely formed soil cover. According to the tonality, sometimes according to the microtexture of the given space photograph one can read the grey-brown and desert-sandy soils, saline soils and alkali soils. Their attachment to the valley and ancient-lake forms is very definitely established. The degree of hydromorphic nature of the natural complexes and the vegetation cover inherent to them are determined.

In the interpretation of the intrazonal meadow and swamp landscapes of the desert the main indicator becomes the vegetation--halophyte meadows, reed thickets, tugai, and others. It is clearly differentiated in the color gamma of the false-colored image. According to the types of territorial associations the delta, flooded swamps, swamps and saline meadows in the layer sands, etc. are detected.

The landscape map compiled from the space photograph whose diminished reproduction is presented in fig. 1 is the first for this region.

The working map compiled in the scale 1:300,000 in details corresponds to the topical maps now compiled in this scale, for example, the soil (minimum size of contours--8-12 mm<sup>2</sup>, saturation--to 3-5 contours per 1 cm<sup>2</sup>). However, we believe that this scale permits compilation of more detailed topical maps with the minimum size of contours on the order of 5 mm<sup>2</sup>. With a reduction in the compiled landscape map to scale 1:500,000, without generalization of the content, a degree of detail is reached which completely meets the requirements of this scale (minimum size of contours 2-3 mm<sup>2</sup>, saturation--to 5-7 contours per 1 cm<sup>2</sup>).

Field works to ensure interpretation of the photographs were continued for one week, laboratory works on interpretation and compilation of the landscape map conducted jointly with the landscape specialist and cartographer occupied about one and a half months. The mapping encompassed an area of more than 34 thous. km<sup>2</sup>. If the mapping, as this is usually practiced, would be conducted with the use of aerial photographs, the time expenditures for the fulfillment of the work would increase several dozen times (the territory is covered by 4000 aerial photographs of scale 1:30,000).

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Compilation of the map by the flight line-key method with the use of topographical maps as the basis for extrapolation of the given spot and flight-line

observations requires a considerably thicker network of routes and points of survey in comparison with those used. In addition, the achieved degree of detail in the contours and the accuracy of their making in the absence of photographic basis cannot be ensured.

The experimental work on compiling landscape maps according to the space photograph indicate the possible ways of using the space photographs for topical cartography. They should serve as the material for extrapolating the data of observations at individual points and on key sections for the entire territory not provided with observations and used as the foundation for more accurate, detailed and sound making of contours and natural borders. An especially pronounced effect is shown by the advantage of using a photographic base in the plain regions, where on the maps serving as the foundation for making the landscape contours, with a comparatively small section of the relief it is often difficult to find the points of surveying and the contours have to be artificially schematized.

The previously undertaken experiment of compiling a landscape map on the territory of the steppe zone of the Altay kray which was conducted in parallel by two methods--without the use of space photographs and with their use--showed that the detail of the map in the second case increased very significantly [3].

Finally, we will stress the exceptional role of space photographs in the operation which is the most complex for topical mapping, typology of the mapped natural target. In this case use is made of color gamma, tonality and texture of the images, configuration and dimensions of the contours, mutual space conjunction (geographic proximity).

The success of the work with the photographs to a great extent is determined by the availability of a rectified picture, essentially photographic maps. The creation of photographic maps from space photographs is a necessary stage in their cartographic use. Especially useful would be photographic maps with contour lines (with nonclogging of the photo-image by the drawing of the relief). It is also expedient to sign on the photographic map the elements of orohydrography which would significantly facilitate the orientation and association of the photo-image to the map. In our variation it was at times impeded.

A comparison of the compiled landscape map with certain specialized topical maps of close scales indicates that with the use of space photographs these maps

can be given in detail and made more exact.

The entire conducted experimental work testifies to the great perspectives of the cartographic use of space photographs, in particular, to the fact that the photographs from resource and not only special cartographic satellites can be used for the purposes of topical mapping on survey scales. At the first stages it is most expedient to combine laboratory interpretation of photographs with standard field work, subsequently, in the accumulation of experience and development of interpretation standards it is possible to transfer to complete laboratory compilation of maps. The expediency of using space photographs for renewing, pinpointing and perfecting the existing maps is natural.

\* \* \* \*

Space photographs of regional scales reflect the landscape structure of the territory immediately on several geosystem levels. They can be used to detect and map both landscape and physico-geographical regions and provinces. Many of the indicated natural regions are reflected and interpreted on space photographs directly as integral formations. At the same time the photographs permit revelation of their internal landscape structure.

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On this foundation a physico-geographical zoning can be made according to the space photographs at once by two means: both from above, from the highest units to the lowest, and from below, from an analysis of the landscape structure to synthesis of the regional system entirety. The latter approach is especially promising in space geography.

With the help of the examined examples we implemented physico-geographical zoning of Western Balkhash region from the ERTS space photograph and the landscape map compiled from it (fig. 2). Our scheme differs from all previously compiled schemes of natural zoning for this territory in its considerably higher degree of detail, accuracy and most importantly, strong landscape-structural substantiation.

\* \* \* \*

Due to the great field of vision, isochronic nature of obtaining the information from a territory considerable in area, repetition of the photography, the space photographs present good material for studying the dynamics of natural and crop landscapes.

For comparison of different-time materials of space photography it is necessary that their scale and resolution do not differ very strongly and are comparable. Therefore, for example, a great effect should not be expected from comparing the photographs from space and the television pictures from meteorological satellites. In addition, the resolution of the photographs must be comparable with the size of the proposed territorial changes. As a consequence of this, the most easily provided repeated photographs from the meteorological satellites cannot always be used to study the dynamics of various components in the natural environment. If such changes as the descent or setting of the seasonal snow cover, the seasonal dynamics of the vegetation encompassing large territories are reflected on them fairly well, then the many-year changes which are relatively insignificant in area, for example, in the placement of the shoreline of seas and lakes, are not always caught by these photographs.

In so far as for the best quality space photographs, those such as photographs from spacecraft, we often do not have different-time analogues, we are forced to resort to comparison of the photographs from previously compiled maps which are close in detail, whereby this comparison in a number of cases is very effective.

The territory of the Balkhash region is provided with photographs from various space vehicles: the spacecraft "Soyuz-9", the orbital station "Salyut" and others. But the most convenient from the viewpoint of studying the dynamics of the landscapes is the photograph taken from the American resource satellite ERTS. Its comparison with the maps published in 1948 permit us to trace certain features in the dynamics of the landscapes in the last 30 years.

In order to reveal the dynamics of the landscapes we selected a comparatively limited circle of elements, those which, on the one hand are clearly reflected on the space photographs and topographical maps, and on the other hand have a definitive value for revealing the extensive complex of changes occurring in the nature of the territory. A comparison was made according to the following elements: on the topographical map--saline lakes, saline soils (with clear contours and without contours) reed thickets on swamps and shore banks; on the space photograph--saline lakes, saline soils, reed thickets. Two networks of the named contours isolated from the 1948 map and the 1972 photograph were compiled separately. These networks were combined by superimposing. The combination had to occur by sections, in so far as the rectification of the photograph envisaged by the system processing of information from the ERTS satellite, as previously indicated, did not completely eliminate



distortions in the picture. Comparison of the photograph and map according to sections, with combination of the picture on individual sections according to "rigid" contours, permits one to avoid the effect of the non-identity of the two images.

In the comparison of the photograph and the map 15 different types of the correlation of the previously indicated dynamic elements of the natural landscape on different-time materials were found. The types of these correlations are shown in fig. 3, while the resulting picture of changes on the studied territory is given in fig. 4. In the analysis of these changes, of course, one should exclude as far as possible errors in depicting the elements we selected on the map. By analyzing the different variants of obtained correlations and results of the cartometric work presented in table 1, one can draw conclusions on the changes occurring on the territory in the last 30 years.

The appearance of lakes on the site of the saline soils indicates a certain flooding of the territory. These newly appeared lakes are noted in single cases on the western shore of Balkhash. On the eastern shore, in the delta of the Ili River there is a considerable expansion of the area of kultuk lakes and the appearance of new lake-kultuks on the site of reed thickets and saline soils. The area of kultuk lakes increased in 30 years by more than twice.

It should be noted that in individual cases there is also a disappearance of the previous lakes and their transformation into sors. Such a sor is observed on the western shore of Balkhash at Tasaral. In so far as the case is singular, it can be classified not because of drying of the territory, but because of seasonal changes. Space photography occurred in the beginning of fall, at the moment of the driest season of the territory; it is possible that in spring and in the first half of summer the sor again becomes a lake.

On a large section in the southeastern corner of the photograph there is complete disappearance of the lake-oxbows along the old beds of the Ili, although next to it, on the lower shore of Balkhash large lakes of the kultuk type formed.

The changes in the salinization of the territory are very considerable. On the western shore everywhere are observed major contours of saline soils on those sites where the 1948 map shows non-saline and free of reed territories. The saline soil areas increased  $1\frac{1}{2}$  times from 5.8% to 8.8% of the area of the studied territory. Most often the reappearing saline soils are confined to the bottoms of large, ancient

valleys. A portion of the dispersed, uncountoured saline soils indicated on the map and located primarily along the bottoms of valleys, is isolated on the space photograph in the form of totally defined contours of continuously salinized territories. This also testifies to the expansion of the dispersed, previously small saline soils to considerable dimensions reflected in the scale of the map and to their fusion into large contours, that is, the increase in the salinized territory.

The reverse picture is also detected on individual sections--territories shown on the map as saline soils are interpreted according to the 1972 photograph as non-salinized sections. However, there are comparatively few of these sections; the "reduction" in area of salinized territory is 1.5 %, while their increase reaches 4.8% of the area of the studied section.

Information on the increase in area of salinized territories is of practical importance. In order that in the conclusions on the increase in salinization there were not included errors of representation of the salinized territories on the topographical map, we made a selective check of the accuracy of the picture of saline soils on the 1948 map by comparing the map with aerial photographs taken at the same period. This check showed that the topographical map correctly reflects the salinization of the territory at the time the aerial photography occurred. /104

The areas occupied by reed vegetation coincide for the most part on the different-time materials. However, in individual places the appearance of new contours of reed thickets was established that are not shown on the map. They are located primarily along the shoreline on the southeastern coast of Balkhash testifying to the stronger swamping of this shore. The reed vegetation also appeared on the site of the sometime pure lakes without reed thickets along the northern branch of the Ili delta.

The reverse phenomenon however is also observed--disappearance of reed thickets shown on the map. These contours are primarily eliminated from the shoreline and located only the periphery of the contours of reed thickets which were unchanged during this time.

The delta arms of the Ili River do not have constant bottoms. They change their position periodically. Therefore the constant change in their surrounding territory, including the delta, reed, overgrown river banks, which it should be said, are excellently isolated on the color photograph due to their bright red color, is

completely natural. It is a consequence of the dynamics of the delta [2].

A comparison of the space photograph with the map permits detection also of a change in the shoreline of the Balkhash Lake. It is true that due to the unclarity of the image on the photograph of the eastern shore of the Balkhash a comparison of the contours on this section was uncertain. In addition, the accuracy of combining the photograph and map implemented for individual sections was not completely sufficient to detect small changes in the shoreline sometimes expressed in dozens of meters. Those changes which reach several hundreds of meters (over 300 m) are well traced. Therefore we successfully established the overall trend in changes of the shoreline.

On the western as well as on the eastern shore there was universal recession of the shore and expansion of the area of the lake. The small inlets became more deeply cut, the small sand bars and islands disappeared. Certain lagoons previously located near the shore were transformed into open bays. The capes oriented to the south on the islands of Basaral, Orgaaral and Oyakaral disappeared. Only in individual cases was the reverse shift noted in the shoreline, the formation of dry land on the site of the lake which can be classified both as a result of the growth in individual accumulative shore forms of the relief, and as a result of the inaccuracy of the combination of the different-time materials.

The results of a comparison of the placement of the shoreline of the Balkhash with an interval of 30 years indicate that the lake level rose. This situation also explains the changes occurring on the land well. With a rise in the level of the Balkhash the level of the subsoil waters also rose on the adjacent land, as a result of which there was a noticeable increase in the area of the saline soils on the western shore, especially for the bottoms of large, ancient valleys. Certain saline soils in the deeper depressions were converted into lake-sors. In the delta of the Ili River as a consequence of the ingression of the Balkhash new, large lakes of the kultuk type appeared which divided the delta branches.

The conclusions made in comparing the space photograph and the map are confirmed by hydrological data characterizing the many-year fluctuation in the level of Lake Balkhash. The graph of the change in the level of Balkhash for the period we are interested in [1], presented in fig. 5, shows that the level of the lake for the last 30 years rose roughly by 2 meters, while in the middle 1940's when it occupied a lower position for this time, by 2.5 meters. Thus, the data of hydrological

TABLE 1

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CHANGES IN AREAS OCCUPIED BY LAKES, SALINE SOILS AND REED THICKETS ON THE TERRITORY OF THE WESTERN BALKHASH REGION OVER 30 YEARS, DETECTED AS A RESULT OF COMPARISON OF A SPACE PHOTOGRAPH FROM 1972 AND A TOPOGRAPHICAL MAP FROM 1948

Type of territory	Nature of changes	Index on scheme of dynamics	Area, km <sup>2</sup>	% of area of studied section
1	2	3	4	5
Lake Balkhash (section represented on photo)	Area in 1972	1 + 15	10121.85	
	Area in 1940's	1 + 14	10013.58	
	Difference		108.27	
	Transgression	15	121.68	1.20*
	Regression	14	13.41	0.13*
Small saline lakes and kultuks	Area in 1972	1 + 2 + 3	366.75	2.69
	Area in 1940's	1 + 4 + 10	141.12	1.03
	Difference		225.63	1.66
	<u>Disappearance of lakes</u>			
	Including:			
	Complete drying of lakes	10	55.17	0.40
	Conversion of lakes into sors	4	23.58	0.17
	<u>Formation of new lakes</u>	2 + 3	304.38	2.23
Including:				
Formation of new lakes on site of saline soils	2	168.66	1.24	
Formation of new lakes on site of reed vegetation	3	135.72	0.99	
Saline soils	Area in 1972	5 + 6	1200.42	8.80
	Area in 1940's	2 + 5 + 11	793.30	5.85
	Difference		402.12	2.95
	Salinization	6	649.35	4.76
	Desalinization	11	201.33	1.48
	Conversion of saline soils into saline lakes	2	168.66	1.24
Reed vegetation	Area in 1972	7 + 8 + 9	639.44	4.69
	Area in 1940's	3 + 8 + 12	556.74	4.08
	Difference		82.70	0.61
	<u>Appearance of reed thickets</u>			
	Including:			
	Appearance of reed thickets on land	11	308.88	2.26
	Appearance of reed thickets on lake site	7	17.64	0.12
	<u>Disappearance of reed thickets</u>	3 + 12	242.82	1.77
	Including:			
	Disap. of reed thickets on dry land	12	107.10	0.78
Disap. of reed thickets with lake formation	3	135.72	0.99	

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observations and the results of comparing the different-time photographic materials coincide, but the latter not only permitted statement of the fact of lake transgression, but also tracing of the changes in landscape of adjacent territories associated with this.

The conducted work testifies to the fact that the space photographs are good material for studying the many-year dynamics of natural landscapes or their individual components. The provision in the future of the same territory with a series of different-time photographs close in quality should expand these possibilities even more.

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The experimental work with the space photograph from the ERTS satellite also indicates that photographs of this type are good material for updating and perfecting maps, in particular, topographical. For example, on the territory we studied the space photograph can be used to correct the position of the shoreline of lakes, contours of saline soils and reed thickets. With the use of the photograph from the ERTS satellite on the scale 1:1,000,000 this updating can be made on maps of the scales 1:1,000,000, 1:300,000, and for certain elements, even 1:100,000.

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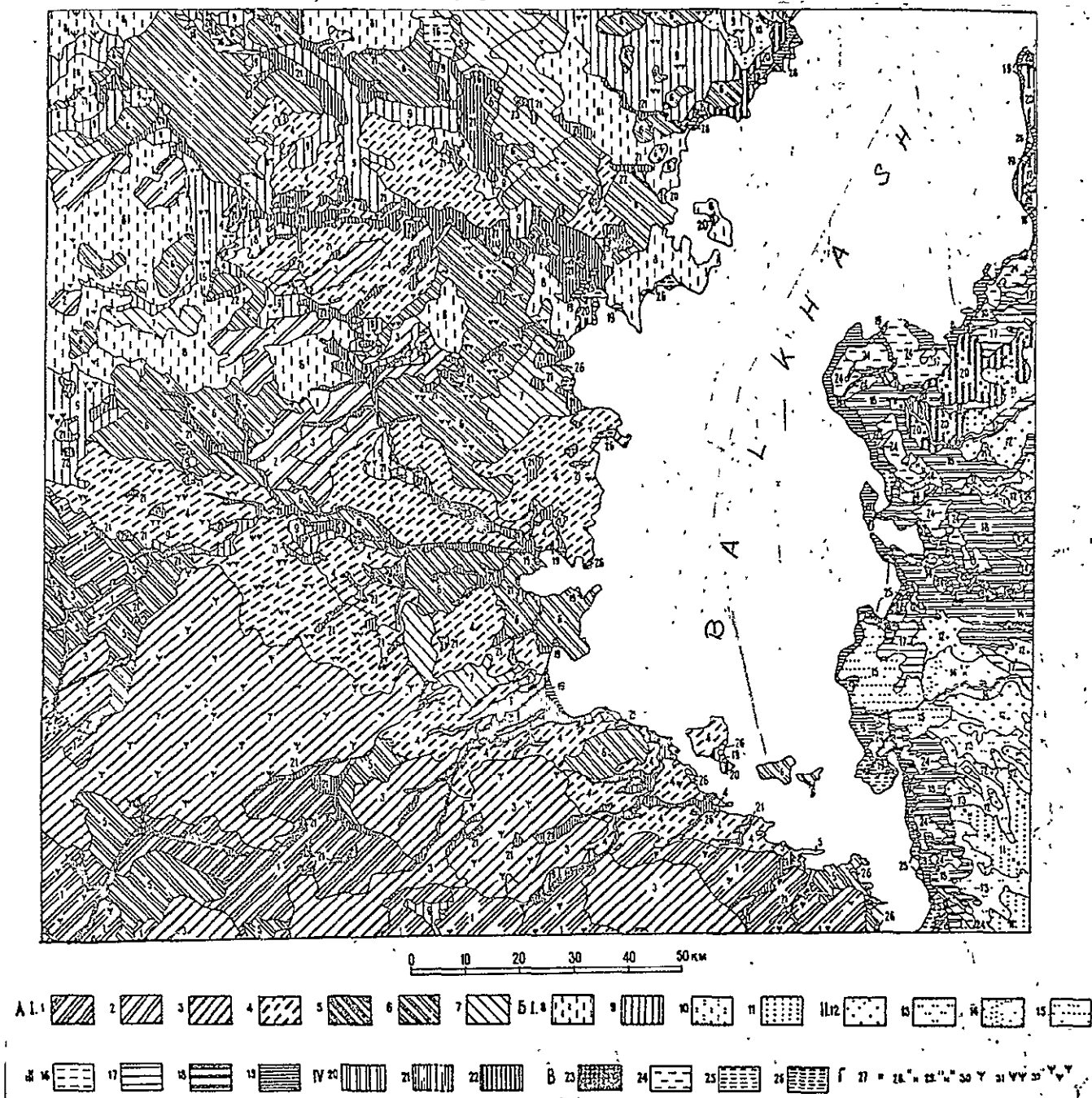


Fig. 1. Landscape map of Western Balkhash region compiled with the use of a photograph from the ERTS satellite.

Landscapes of desert in temperate zone: A. Low-mountain and small cone-shaped hills.  
 1. Desert; 1. Erosion-denudation low-mountains, broken up, composed of metamorphic rocks of lower Paleozoic era and Protozoic era (quartzites, silicon shale, etc.), rocky, with stone streams on slopes, with complex of wormwood-boyalychev, wormwood, Anabasis and Tas-anabasis associations on the mountain, grey-brown, detrital soils. 2. Erosion-denudation low-mountains, composed of acid effusive rocks of middle Paleozoic era (porphyry, albitophyry, etc.), rocky with stone mounds, with wormwood-boyalychev, Tas-anabasis and Anabasis associations on mountain, grey-brown /109 detrital soils and wormwood-elm thickets in ravines. 3. Arid-denudation high plateaus composed of paleozoic granitoid rocks, partly outcropped (to 20-25% of area), with





dispersed wormwood-boyalychev, wormwood-hemp, wormwood-winterfat and Tas-anabasis desert associations on mountain grey-brown gravelly-detrital soils. 4. Erosion-arid-denudation small cone-shaped hills, broken up, hilly-ridge, composed of sedimentary, dislocated rocks of the middle and upper Paleozoic era (sandstones, shales, silicon limestone), with wormwood-boyalychev Tas-anabasis and Anabasis desert associations on grey-brown, underdeveloped detrital soils. 5. Erosion-arid-denudation small cone-shaped hills, flattened, slightly broken up, composed of metamorphic rocks of the lower Paleozoic era and Protozoic era (quartzites, silicon shales, etc.), with wormwood, wormwood-boyalychev, Anabasis-Tas-anabasis desert associations on grey-brown underdeveloped detrital soils. 6. Erosion-arid-denudation small cone-shaped hills, ridgy-hilly, composed of acid effusive rocks of middle Paleozoic era (porphyry, albitophyry, etc.), in places rocky with stone razvals\* and mounds, with wormwood-boyalychev, wormwood-ebelekov, Tas-anabasis and Anabasis desert associations on grey-brown underdeveloped detrital soils. 7. Erosion-arid-denudation small cone-shaped hills, large hills (dome-shaped, cone-shaped, ruins), composed of paleozoic granitoid rocks, strongly outcropped, rocky with wormwood-boyalychev, wormwood-hemp, winterfat-wormwood, Tas-anabasis desert associations on grey-brown underdeveloped gravelly-detrital soils. 5. Plain.

I. Desert: 8. Arid-denudation foundation plains, gently sloping ridges, composed of effusive-sedimentary rocks of folded Paleozoic era, partially recovered with ancient kaolinite weathering crust, with a complex of wormwood-boyalychev, wormwood, Anabasis and kokpek desert associations on grey-brown loamy detrital soils and desert alkali soils. 9. Alluvial benches--bottoms of ancient river valleys, planar and plano-rolling, composed of sands and pebbly, with cover of aleurites and loams, with grey wormwood, boyalychev-grey wormwood, black wormwood-kokpek and Anabasis desert associations on grey-brown light loamy soils and desert alkali soils. 10. Aeolian plains, hilly and ridgy-hilly, friable-sandy, on ancient alluvial base, with wormwood, wormwood-erkek desert associations on sands attached with outcropped, scattered masses. 11. Aeolian ridge sands on alluvial base, lightly anchored with desert bushes of saxaul, zhuzgun, winterfat, with thinned cover of swelling-fruit-bearing sedge, Ephedra, Kochia. II. Saline soil-meadow-desert: 12. Aeolian ridge near-delta sands on alluvial base, lightly anchored by desert bushes of saxaul, zhuzgun, chingil, winterfat; with halophytic meadows and wet saline soils in inter-ridge depressions. 13. Aeolian ridge near-delta sands on alluvial base, lightly anchored by desert bushes of saxaul, zhuzgun, chingil, winterfat, with shoal drying up lakes and reed thickets in inter-ridge depressions. 14. Delta-alluvial benches--along river bed swells, hilly, sandy, surface-shifting, with thinned bush tugay of chingil, tamarisk, elaeagnus. 15. Delta-alluvial plains--benches of middle and high level, sandy loam-loamy, with thinned bush tugay of elaeagnus, chingil, tamarisk on alluvial desert soils. III. Meadow and swamp: 16. Alluvial, backwater benches, sandy loam-loamy, with wormwood-halophyte-grassy meadows, thickets of chen, tamarisk, chingil on meadow saline soil soils and meadow alkaline soil-saline soils. 17. Delta-alluvial plains--benches of middle and lower middle level, sandy loam-loamy, with halophytic-grassy meadows and wormwood-saltwort associations on alluvial meadow saline soils. 18. Delta alluvial-lake low plains, muddy-loam, with thickets of reeds on meadow-swamp and flooded soils in combination with small kultuk lakes. 19. Lake shore shoals and sand bars, muddy-sandy, with thickets of reeds and saltwort-halophytic-grassy meadows and weakly formed saline soils. IV. Saline soil: 20. Alluvial-lake (ancient-delta) low plains-benches, sandy loam-loamy, with thinned succulent saltwort associations on puffy and crusty saline soils. 21. Alluvial and lake low benches--bottoms of ancient river valleys, troughs and lake hollows composed of sandy loams, aleurite, loams, with succulent saltwort vegetation on saline soil crusty and puffy, kokpek and Anabasis associations on alkaline-saline soils in combination with sor saline soils. 22. Ancient-lake and ancient-valley

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\*Translator's note: disintegrated blocks piled up on mountain slopes.

(Continuation of legend for fig. 1)

depressions with sor saline soils. B. Aqual; 23. Drying up saline lakes. 24. Delta silting up lakes of kultuk type. 25. Near-delta silting up lake shoal water. 26. Partially submerged (as a consequence of lake transgression) low lake shores.

Г. Subordinate natural boundaries. (with indication of the area in % occupied by them in the landscape contour). 27. Halophytic meadows--to 3%; 28. Halophytic meadows--to 5%. 29. Halophytic meadows--to 10%; 30. Saline soils--to 3%; 31. Saline soils --to 5%. 32. Saline soils--to 10%.

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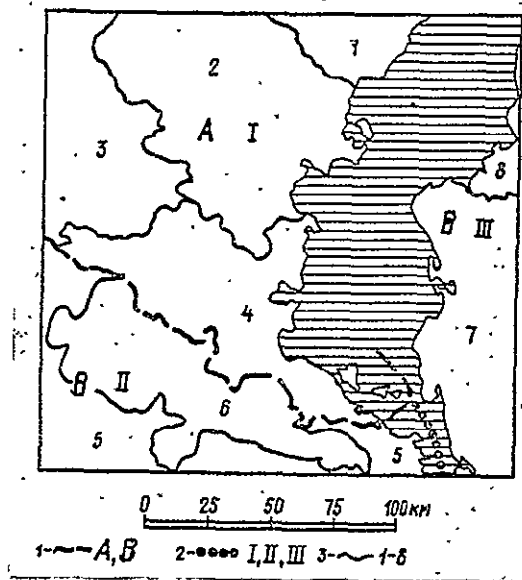


Fig. 2. Physico-geographical zones of Western Balkhash region. Indices and natural borders: 1--country, 2--province, 3--regions. A. Central-Kazakhstan Physico-geographical country. 1--Province of Northern and Western Balkhash region of plain-small cone-shaped hill desert. Regions: 1--Gul'shad--ancient-valley clay-desert and sandy-desert; 2--Sary-Shagan--small cone-shaped hill, stony-desert, valley-saline soil; 3--Kysylkingir--heightened-plain stony-desert; 4--Myn-Aral--ridge-small cone-shaped hill, stony-desert, valley-saline soil; B. Dzhungaro-Tyanyshan physico-geographical country. II. Chu-Ili low-mountain semidesert-desert province. Regions: 5--Burubaytal--high plateau-small cone-shaped hill stony-desert; 6--Kaib--high plateau-heightened-plain stony-desert; III--Province of Southern Balkhash region plain desert. Regions: 7--Lower-Ili-delta flooded-sandy-desert; 8--Bakanas--ancient delta sandy-desert, clay-desert and saline soil.



A

On photograph \ On map	Lakes clean and with reed vegetation	Saline soils	Reed vegetation on swamps, sands, saline soils	Unsalinized and not occupied by reed territory
Lakes				
Sors				
Saline soils				
Reed vegetation				
Unsalinized and unoccup. by reed terr.				

B

On photograph \ On map	Dry land	water
Dry land		
Water		

Fig. 3. A. Correlation of contours of saline lakes, sors, saline soils and reed thickets revealed during comparison of 1948 map and 1972 space photograph. B. Correlation of contours of water area of Balkhash revealed during comparison of 1948 map and 1972 space photograph.

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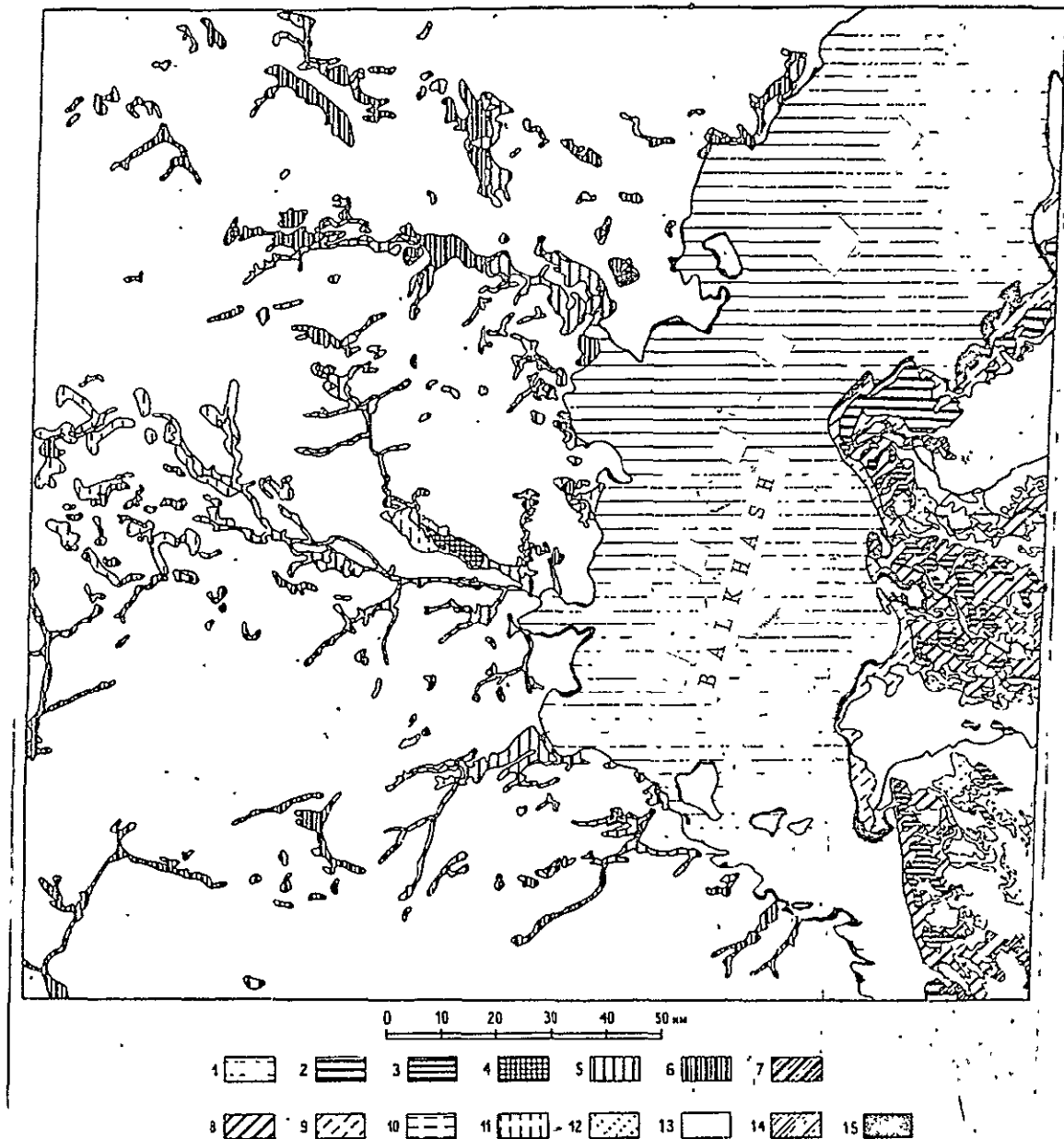


Fig. 4. Results of comparing 1972 space photograph and 1948 topographical map: 1--lakes whose image on the photograph and on the map coincide; 2--saline lakes appearing on the site of saline soils; 3--lakes appearing on the site of reed vegetation; 4--sors formed on the site of dried up saline lakes; 5--saline soils whose image on the photograph and on the map coincide; 6--saline soils appearing on the site of unsalinized and unswamped territory; 7--reed vegetation appearing on the site of saline lakes; 8--reed vegetation whose image on the photograph and map coincide; 9--reed vegetation appearing on the site of unsalinized and unswamped territory; 10--unsalinized and unswamped territory on the site of saline soils shown on the map; 12--unsalinized and unswamped territories on the site of disappeared reed vegetation; 13--unsalinized and unswamped territory whose image on the photograph and map coincide; 14--dry land appearing on site of Lake Balkhash; 15--Water area of Balkhash on site of flooded dry land.

[Translator's note: No. 11 omitted from original foreign text.]



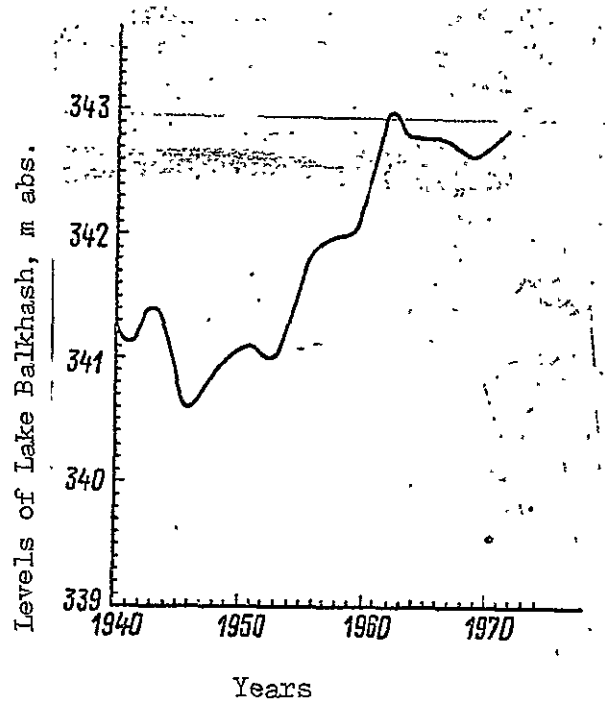


Fig. 5. Fluctuations in level of Lake Balkhash for the period 1940-1972. [1]

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D. S. Asoyan

There has been little study of the possibilities of using space television images (TVI) in the geomorphological research in various natural zones of the USSR and interpretation signs of the relief. As for the latter question, in our opinion, it has not been given sufficient attention in the available works on the geographical and geological interpretation of small-scale space images.

Meanwhile, a study of the interpretation natural components is necessary in order to answer a number of procedural questions: first, to develop a technique of interpretation and in particular, solution to the problem of the possibility of extrapolation of interpretation signs of the natural targets on small-scale space images; second, scientific substantiation of the "generalization effect" of space images; third, detection during analysis of the signs of new possibilities for using the images.

Our research established that on global and small-scale TV space images, the signs of the natural targets are primarily tonal differences governed by differences in their spectral reflective ability, and the illustration of the image. On local photographs (obtained from piloted craft--PC) shape, shade and dimensions are also separated. As a consequence of this, on the small-scale space images the relief and other components in the majority of cases are represented by indirect signs which are successfully detected through a complex series of interrelationships of natural components and natural-territorial complexes (NTC).

All of these circumstances, on the one hand, complicate study of the interpretation signs of the relief elements, and on the other hand, permit detection, thanks to the optical and geometrical integration of the image, of such features of its structure which are masked by details represented on the TVI from the ERTS and photographs from PC ("Salyut", "Gemini"). For example, certain river valleys on the TVI of arid regions (the Vakhsha River basin) are indirectly manifest, as this will be shown in this article, through integration of the optical properties of the indicators--high turbidity of water, alluvial deposits of islands in the bed and bottom of valley.

On the images with higher resolution on the site (ERTS, "Salyut") these features

are lost in the details of the image of river valleys.

In relation to the aforementioned, we attempted to determine the possibilities of using TVI in geomorphological studies and to investigate the interpretation signs of different relief elements.

The conducted research showed that the interpretation signs of the components of the nature and the NTC on the TVI apparently for now may be studied on the basis of aerial-visual observations of their spectral intensity with maximum permissible generalization of the observations and detailed ground work on the key sections. For the given studies this method permits one to obtain in a number of cases satisfactory results and the interpretation signs of natural targets on the small-scale images can be studied more fully in our opinion: first, only by obtaining quantitative data on the spectral intensity of the natural targets; second, by achieving that accuracy of geographical linking of the results of measurements that will corespond in accuracy and resolution on the site to the examined images.

The article has been written on the basis of laboratory and field work in 1971-1975.

#### Possibilities of Using TVI in Geomorphological Studies

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In order to find the possibilities of using TVI materials were examined from photography of the meteorological satellites "Kosmos" and "Meteor" from 1967 according to the catalogue of satellite data of the Hydrometeorological Scientific-Research Center of the USSR.

Photography from the 1-10 AES (artificial earth satellite) "Meteor" occurred from an altitude of 680-720 km on a zone of double-frames on a scale in the center of the image about 1:7 mill., with width of the zone of photography about 610 km, length 820 km. In its real resolution the TVI from "Meteor" and "Kosmos" (2-6 km) is inferior to the photographic space images, nevertheless it is a more operative and accessible type of information. Moreover, in recent years the quality of the images of the photography materials from the AES "Meteor" have been improving more and more (fig. 1-I) (M. 1:10,000,000).

On the territory of the USSR we studied the TVI free of cloud covers of various large geostructural regions located in different natural zones; and for each region,

in turn, according to the seasons and different days. On the whole over 500 images were examined (television montages) on the territory of the tundra zone: Eastern Siberian lowland, forest zone--European section of USSR, Vilius lowland, Aldan and Yano-Oymyakonsk uplands of the Verkhoyansk crest, Far East, Kamchatka, plains and mountains of Central Asia and the Caucasus.

An analysis of the TVI showed that the possibilities for studying various types of relief on them are ambiguous. They depend on a combination of different circumstances: time factors--weather, season of photography, specifications, and most important, on the features of the natural conditions and the optical properties of the landscapes governed by them and consequently--the interpretation signs. With different combinations of these factors their information content differs sharply. It is thereby not excluded that each frame (or zone) of the television photography has its unique information.\*

At the given stage of studying the relief of mountains and uplands in different natural zones, it can be considered that the most informative are the TVI from 1-10 AES "Meteor" for the winter-spring seasons; they can thereby be used with specific limitations--nonuniform occurrence and thickness of the snow cover which indicates the relief and with relative breakup of the relief  $\geq 300-500$  m (mountains of Yakut, south Siberia, Transbaykal and Caucasus; fig. I, II-IV, VI, VIII). At the same time, the TVI are evidently of little suitability for studying the relief of the low mountains due to the low space resolution (Alday uplands, Yano-Oymyakonsk uplands, etc.; fig. 2). A certain exception is the mountains of the arid zones with melt water puddles and glaciers. For these regions TVI can be used, except for the winter and summer season, depending on the interpretation signs of the relief (fig. 1, I, V, VII).

The photographs of TVI from the 1-10 AES "Meteor" are apparently of little suitability also for studying the plains of the temperate zone regardless of the season. This is explained by the masking role of the snow cover (winter) and the vegetation cover (summer) (fig. 1, II).

In relation to this, satisfactory interpretation can be made with a specific collection of images for the same territory (not less than 2-3) which is necessary for mutual supplement, control of the results and calculation of various obstacles.

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\*All the factors forming the TVI still remain unclear; therefore, the analysis we made does not claim to exhaust the solution of this problem.



The possibilities using the TVI from the 18th AES "Meteor" are broader due to the improvement in the quality of the images and photography in different zones of the spectrum. They are favorable for studying the mountain and low-mountain areas /116 in the winter period, for example, the Yano-Oymyakonsk upland; the possibilities of studying the latter also depend on the interpretation signs of the relief. The TVI from the 18th AES "Meteor" may be used for plain territories with small absolute elevations in the relief of the forest zone and in the winter and summer period under the same condition--depending on the signs of the natural targets (degree of freezing of rivers in North ETS [European Territory of Soviet Union], degree of snow cover of negative relief forms in Central Yakut, of contrasts in the nature of the vegetation cover in West Siberia governed by the features of the relief structure, the composition of precipitation, etc.\*). Thanks to the photography in the near infrared zone (0.8-1.1) the TVI can be used to study the plains of the steppe and dry-steppe zone (south of the European territory of the USSR, Kazakhstan and Central Asia)\*\*.

In order to determine the possibilities of TVI from the 1-10 AES "Meteor" on the example of two large regions we conducted geomorphological interpretation of a series of images of the "Meteor"--Pamro-Alay and north Yakut (fig. 1, II, IV, V-VI, fig. 2, 3). The TVI were interpreted both according to the original and according to 1.5 times enlarged prints on an interpretoscope with enlargement of the optical system to 5x.

The results of these studies showed that for the geomorphological purposes the TVI obtained in the visible zone of the spectrum give new information for studying the systematic configuration of the river network of entire river basins and the features of the river valley structure; they permit one to find the connate and redeepened valleys, to study certain laws governing the formation of major features in the relief, to reveal the largest, linear and block morphostructures. Thus, the possibilities of using TVI in the geomorphology differ considerably from the space local photographs (Vinogradov, Grigor'yev, 1970; Meshcheryakov et al, 1971). Under specific conditions the TVI can be employed to conduct the aforementioned small-scale studies, while the latter can be used to obtain more comprehensive and detailed information about the relief, but on a more limited area.

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\* Winter TVI from the 18th AES "Meteor" (resolution on site 1.5-2 km) are more informative for studying the relief in comparison with the summer.

\*\* At the same time for studying not only the morphostructure but also the morphosculpture.

## Results of Studies of TVI for Pamiro-Alay

For the given territory there are a number of TVI from the AES "Kosmos-226" (fig. 1, IV; fig. 3), "Kosmos-184", "Meteor" (fig. 1, VI), "ESSA". One of the informative ones for the established goals is the TVI from the AES "Kosmos-226" obtained September 3, 1968 at 12 h 48 m.

## Interpretation Signs of the Relief Elements

At the given stage of research, not relying on special measurements of the coefficients of spectral intensities, we conducted a study of the interpretation signs of the relief elements by: a) aerovisual observations and visual assessment from altitudes to 3000-4000 m\*\*\*\*,\*\*\*\* of the spectral intensity of the natural complexes formed on large shapes of the relief; photographing of the relief elements on color and black and white film and further comparison of the space distribution of the spectral intensity with the density of tone in the TVI; b) successive ground study of the features in the structure and evaluation of the spectral intensity of each component separately and detection of the degree of their effect on the overall color and intensity of the NTM: 1) relief (morphology, degree of breakup, microrelief); 2) composition of rock (degree of weathering of outcropped rock, color and mechanical composition of surface, friable sedimentations); 3) nature of moistening; 4) nature and distribution of vegetation cover (degree of projective cover); c) detection of the reasons for differences in the interpretation signs of river valleys similar in the peculiarities of their structure (for example, differences in the signs of valleys in the basin of the Vakhsh River and the Sokh River).

In the center of the examined TVI there is Fergan hollow expressed by an indirect sign--vegetation crop in regions of the development of irrigated agriculture governing the dark grey phototone of the image and isolated on the background of piedmont regions. The latter are expressed by the light grey phototone and are forms of proluvial genesis devoid of a vegetation cover (debris cone and harrows of varying age); they are composed of neogen-quaternary molasse which possess a considerable

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\*\*\* From the helicopter MI-4 with necessary landings on previously marked sections for ground observation (collection of herbarium, samples of rocks, water, etc.)

\*\*\*\* The intensity of the targets was conventionally evaluated in relation to the intensity of the outcroppings of light rocks (limestones, granites) and exposed sandy and pebbly floodplains according to a five-point system.



reflecting ability. Thus, these relief forms are also expressed indirectly--by the composition of sedimentations (optical properties of friable deposits of considerable thickness are unclear and require more study). The massifs of unanchored sands in the center of the hollow and sands in the desert of Kyzyl-Kum (upper left corner of the photograph) are expressed in the same tone.

The mountain ridges are isolated by a dark grey phototone and their most elevated axis sections are shown by meltwater puddles (mountains of West Tyan'-Shan') and glaciers of South Tyan'-Shan' and Pamir. This tone, from our viewpoint, is governed by the considerable vertical breakup of the relief which in turn governs the large percent of steep slopes and shaded sections, their overall "pittedness" of the surface. The cloud cover conceals East Pamir and the adjacent regions of China from direct observation (lower right corner of photograph).

The river valleys are expressed in various ways on the photograph. The rivers of the basins of the Vakhsh River and Zeravshan River are fairly clearly distinguished according to the lines or bands of light grey phototone. Such rivers as the Isfara, Sokh and others which flow from the Alay and other ridges, are expressed only on separate sections by a dark grey or almost black tone depending on the intensity and area of development in the valley of irrigated agriculture. In order to study the causes of the differences in the interpretation signs we conducted laboratory, field and aerovisual observations (1971, 1973) in the aforementioned regions and river valleys. As a result, at the given stage of work it can be stated that the interpretation signs of the river valleys are governed by the following factors:

a) considerable quantity of suspended material in the Zeravshan River and transit rivers of the basin of the Amu-Dar'ya River (Vakhsh, Surkhob rivers and others), which results in the silting up of the disappearing tributaries and irrigation structures. According to our ground observations the greatest turbidity distinguishes rivers flowing from the ridges of the Pyëtr 1st and Vakhsh which are composed of sedimentary mesozoic rocks; on the other hand, rivers flowing from the ridges of the Kabut-Krym and Karategin and composed of crystalline rocks (for examples the rivers Sorbog, Yakhrych) are distinguished by insignificant turbidity.\*

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\*Analysis of the water samples taken by us from different rivers shown and not shown on the TVI showed that, for example, the rivers Surkhob and Sorbog (the latter is not shown on the TVI) do not have differences in mineralization, turbidity is the greatest in the Surkhob River ( $260 \text{ g/m}^3$ ), is insignificant in the Sorbog ( $20 \text{ g/m}^3$ ). According to the data of G. V. Lopatin (Chediya, 1970) the mean annual turbidity of the Vakhsh River is  $3730 \text{ g/m}^3$ , Varzob-- $825 \text{ g/m}^3$  (not shown on the TVI).

This peculiarity is characteristic for the majority of rivers distinguished by a light grey tone on the TVI;

b) the redeepened nature of the valleys (Nikonov, 1971; Chediya, 1971), their /118 antiquity of the laying and development, and as a consequence of this the irregular thickness of the alluvial, boulder-pebble deposits: (rivers: Vakhsh, Surkhob, Obikhingou with tributary Obi-Mazar, right tributaries of the Pyandzh River--Obi-Mazar, Shurob-Dar'ya, Yakhsu);\*

c) the development in the river beds (Vakhsh, Surkhob, Obikhingou) of a large number of islands composed of sands and pebbles and covered with a layer of loess-like loam 5-6 mm thick. In the dry state the surface of the loess-like loam is cemented, that is it has a smooth surface finish. The overall color of the surface of the islands is light grey or blue-grey. All of these facts govern their considerable reflecting ability which is analagous to the reflecting ability of the surface of snow, flashing water and saline soils.

Thus, the river valleys of the basin of the Vakhsh River and the Zeravshan River and others are shown on the TVI through such indicators as the turbidity of water, alluvial-proluvial deposits of considerable thickness in the redeepened ancient valleys and alluvial deposits of islands in the bed which possess high spectral reflecting ability. In other words the river valleys are expressed through integration of the optical properties of their indicators. It should be noted that comparative analysis of the different-scale space images of the given territory and similar others ("Zond-5", AES "Meteor", PSC "ERTS") indicates that the spectral intensity of certain natural targets and their differences are more clearly expressed on the photographs only at a specific level of generalization of the space images. These are apparently, television and global images with resolution on the site of 1.5-6 km.

In relation to this, despite the low resolution of the TVI and of global photographs it is possible to also study the peculiarities of the structure of targets or their differences which determine their optical properties--water turbidity, geographic ranges of the development of genetically uniform friable deposits, weathering crust, etc.

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\* Recently ground data have been obtained on the possible redeepening of the valleys of the rivers Sokh, Isfara not shown on the TVI.

## Structural-Geomorphological Interpretation of the TVI

On the example of a large amount of factual material it was established that the linear elements of the landscape, and mainly of the river network (lineaments), reflect the laws governing the structure of the planetary fracturing and faulting tectonics (Shul'ts, 1972). The high field of vision and natural generalization of the space images permit detection of the linear sections of large river valleys which developed planetary fissures and faulting structures of high orders. These valleys are the most reliable signs in comparison with other elements of the relief or natural components and cannot always be found on topographical maps.\*\*

The compliance of the river valleys to the faulting disorders is established in each specific case separately by the technique we developed. With the compliance of the lineament to the breakup zone with considerable width, it can be considered a three-dimensional formation--linear morphostructure (or morphostructural lineament according to I. P. Gerasimov and Ye. Ya. Rantsman, 1973). For the qualitative differentiation of the lineaments for those tectonically determined and related to planetary fracturing methods were used of morphostructural analysis of their features of structure and of adjacent territories: study of deformations of geomorphological 119 levels (surfaces of leveling, river benches), of the intensity of density of erosion breakup and fracturing, analysis of the geophysical data. A study of the linear morphostructures is important for understanding the features of the structure, laws governing the formation of the relief, history of development, as well as for mapping the block morphostructures. In turn, detection of the block morphostructures whose development is determined in time and space by the given lineaments; allows one to predict the plan of structure not only of the upper sedimentary cover, but also of the deep structural levels--the foundation and horizontal sections of the earth's crust (Asoyan, 1975).

In addition, besides the qualitative differentiation of the lineaments, the methods of morphostructural analysis permit detection of such lineaments which correspond to the faulting young or "rejuvenated" ancient (?) disorders not shown in the geological structure; these disorders play an important relief-formation role and are discerned only by deformations in the geomorphological levels, the

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\*\* Careful analysis of the illustration of the Obikhingou River according to the topographical maps on a scale from 1:100,000 to 1:2,500,000 did not permit detection of the linearization nature of the section on the northwest lower portion of the river, while it is clearly expressed on the TVI (fig. 1, V).

nature of the erosion breakup, the development of zones of fracturing, nonuniformity of the geophysical fields and seismic activity.

It should be noted that these possibilities of the morphostructural analysis are still underestimated and not sufficiently employed in the geological-geomorphological interpretation of space photographs. We will attempt to illustrate the given conclusion in the example of the indicated regions of Pamiro-Alay and Yakutiya. It would also be appropriate to add here that the questions of the genesis of faulting, disorders detected by morphostructural methods and their position in the geological structure and other questions are not treated by us. However, if the faults are shown in the modern relief and consequently are neotectonic formations, then the geomorphological data can be used to solve the reverse task--to explain certain questions in the latest history of their development and to determine the presence of shifts and conditionally--their amplitude.

According to the data of TVI interpretation (fig. 3) of Pamiro-Alay a number of lineaments were isolated with clear interpreted signs--linearized sections of river valleys and the interrelation of such valleys of different river basins a distance from 45 to 100-200 km. These lineaments are well recognized on the topographical maps and are confined to the valleys of the Surkhob River and its large tributaries: Yarkhych, Yagman, Obikhingou, Muksu, Kysylsu, individual sections of the Vakhsh River, Vanch River and the right tributaries of the Pyandzh River--Shyrob-Dar'ya River, Obi-Mazar, Yakhsu and to a separate section of the Pyandzh River. Half of them are confirmed by geological and geophysical studies. Thus, according to these data they are primarily zones of breakup of plutonic breakups (in the valleys of the rivers Kysylsu, Surkhob and Vakhsh they correspond well to the studied Gissaro-Kokshaal' plutonic fault, in the valley of the river Vanch-Vanch-Tanymass, according to the northeast section of the central Obikhingou-Khingou) (fig. 3). The remaining lineaments are unknown and have not been studied. They have interpretation signs similar to the signs of the breakup zones of plutonic faults, and in certain cases--Khingou-Vanch--even more clear, therefore may be tentatively associated with similar fault structures.

The lineaments with weak interpretation signs are distinguished by linear changes in the tonality of the television image of the relief and sharp outlines of the axial sections of watersheds which are indicated by the linearized borders

of glaciers and meltwater puddles.\* It should be noted that on the TVI we isolated lineaments of various orientations, with the exception of meridional which may coincide with the longitudinal direction on the TVI lines of the television scan.\*\* /120 Therefore these lineaments were a fortiori not analyzed.

From the data obtained under field conditions by ground and aerovisual observations we studied the lineaments corresponding to the known Surkhob fault (sections of the Gissaro-Kokshaal' or Vakhsh plutonic fault) and the unknown, first isolated from the TVI--Khingou-Vanch (Fin'ko, Asoyan, 1972; 1973a, b; Asoyan, Setunskaya, 1973) and lineaments in the middle and upper current of the River Obikhingou. All of them are shown on separate sections according to the data of aerovisual observations in the linearized form of these river valleys primarily in the middle and upper sections of the near-valley slopes. The river beds within the lineament zone have various forms--both linearized and winding. In the latter cases, with the development of a series of downcut windings, like for example, the Obikhingou River, the linearized form of the valley is masked and is distinguished only on the TVI.

As a result of the interpretation of the Surkhob fault by TVI and aerial photographs on the scale of 1:50,000 and field studies we attempted to pinpoint the position of the borders of this fault which is controversial at present (Fin'ko, Enman, 1971). The zone of the fault, according to the latest structural-geomorphological data includes near-valley sections of the Surkhob River and on the northern slope, the Pyëtr 1st ridge and the southern--the ridges of Kabut-Krym. According to the data of interpretation of aero- and television images, field and aerovisual observations in the breakup zone of the Surkhob fault we included the entire ridge of Pyëtr 1st with latitudinal structural-predetermined fault benches developed on the folding-block substrate and we put the southern border on the southern slope of the crest--along the latitudinal section of the valley of the Surkhsu River\*\*\*. To the north from the valley of the Surkhob River the zone includes the crest of Kabut-Krym roughly along the latitudinal section of the

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\*These lineaments are transferred to the topographical base approximately, nevertheless they may be used as a basic criterion of linear morphostructures for the more-large-scale materials.

\*\* This deficiency is essential in studying the lineaments and already is lacking on the images of the "Meteor" system which are more advanced in quality (M. 1:10,000,000).

\*\*\*According to aerovisual reobservations the valley has a clear linearized form.

Komarou River. The overall width of the zone is thus 30 km. The basis for this conclusion is the concentration here of active, newest latitudinal breakups and their weak development beyond the zone. The southern border is more pronounced in this sign. Another basis for the separation of these borders of the zone is the confinement to them, as well as the accumulation within the zone of epicenters of earthquakes; outside of it they develop sporadically and are again observed already in the zone of Outer Darvaz\* (Gzovskiy et al., 1958).

In order to study the information content of the TVI from "Kosmos-226" we interpreted the lineaments according to small-scale aerial photographs on the section of the intersection of the Surkhob and Khingou-Vanch zones--the lowlands of the rivers Surkhob and Obikhingou (fig. 4). Comparative analysis of the interpretation data indicates that both according to aerial photographs and according to TVI three zones are distinguished--a short latitudinal--from the very mouth of the Obikhingou River on its latitudinal section, meridional (from Novobad mountain in the north to the lowlands of the Obikhingou River in the south) and the northeast (from the mouth of the Obikhingou River to the Novobad mountain. Together these zones enclose a triangular-shaped block which is clearly marked on the TVI in the form of a triangular-shaped spot of a light grey tone governed by the development of alluvial-proluvial deposits. This tectonic center was established by the studies of Ye. Ya. Rantsman. At the same time, the latitudinal zone of the Surkhob fault (from the Novobad mountain/121 to the Garm mountain) and the northwest zone--Khingou-Vanch (lowlands of the Obikhingou River) according to the data of interpretation of aerial photographs are not shown. They are lost in the comparatively uniform network of lineaments of the intersecting directions.

Thus, according to the TVI, thanks to their natural generalization of the image of the site, zones of large lineaments of varying orientation were isolated in a large number and with fewer losses of time in comparison with interpretation of aerial photographs (a labor-intensive process under conditions of similar erosion breakup of the relief).

The Khingou-Vanch lineament is shown on all the previously mentioned TV images and extends from the mouth of the Vanch River along the valley of the Pynadzh River

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\* In relation to the establishment of the southern border of the breakup zone in the Surkhob fault along the latitudinal section of the Surkhob River, we isolated the Kugi-Kamch mountains as an independent morphostructure. A confirmation of this is also its inversion nature and the greatest amplitudes of the newest elevations in this region of the ridge of Pyëtr 1st.

(along the northeast section to Kalan-Khumb) across the Khaburabat pass along the northwest section in the low parts of the Obikhingou River, and further to the north, roughly to the upper parts of the Yagnob River. The most clearly interpreted signs of the lineament are confined to these two river valleys. The overall length of the lineament is 200 km (fig. 3). The width of the zone (conditionally established already from the interpretation data of aerial photographs) is 5-7 km. Consequently, this lineament may be accepted as the linear morphostructure. According to geological data, the faults here are not shown. From the complex of geomorphological and geophysical data it can be hypothesized that the lineament corresponds to the fault zone with deep penetration into the earth's crust. This is indicated by the following data. According to geographical seismic studies on the section--from Kalan-Khumb to Tavil'-Dara across the Khaburabat pass--a plutonic fault zone is distinguished which coincides with the lineament zone with amplitude of shifting of the border of Mokhorovichich about 5-8 km (according to geographical data).

According to our field observations and the results of interpreting the aerial photographs, the Obikhingou River valley on the northwest section is laid along the zone of intensive tectonic fracturing. The formation of downcut wanderings of the Obikhingou River is governed by the system of diagonal and orthogonal fissures and the linearized nature of the northwest sections is clearly traced from aerovisual observations. According to the data of profiling of the river benches in the lower accumulation stage here are distinguished deformations of the benches of Holocene age, and according to the data of re-leveling, also the current movements in individual small blocks in the valley (Fin'ko, Asoyan, 1973a, 1973b). The deep laying of the entire linear morphostructure is also indicated, besides the aforementioned geophysical data, by the centers of earthquakes recorded here. All of these data permitted us to hypothesize on the buried nature of the fault, to whose zone the Obikhingou River valley is confined (Asoyan, Setunskaya, 1973). However, as a result of the study of ancient surfaces of leveling in the Obikhingou River basin by V. K. Kuchay, deformations were found in the Pleistocene surface with amplitude about 400 m and our previously made conclusion on the confinement of the valley to the zone of the fault breakup was confirmed. These last data change the idea about its buried nature and indicate its latest activity. It follows from here that the formation of the northwest, young cross-section of the Obikhingou River is associated not with the antecedent downcut of the river (Chediya, 1971) but with the activization of the tectonic zone.

The lineament also plays a noticeable relief-forming role. Along the Pyandzh

River valley, the Darvaz ridge separates from the Safedkhirs massif and determines the echelon substitution of the Khozratishokh ridge by the northeast ledge of the Darvaz ridge and the surface linking of the ridges of Pyëtr 1st and Vakhsh distinguished by the intensity of the newest elevations. In relation to this, in our opinion, the latter two regions should be classified with the isolated, independent orographic elements, and not with the unified system as is proposed by O. K. Chediya (1971).

Thus, one can consider that the Khinguo-Vanch lineament corresponds to the zone of breakup of the active, newest fault with deep penetration into the earth's crust at certain sections, and consequently, also has a long history of formation. Analysis of the history of the relief development and of geological structures in the breakup 122 zone will help also to illuminate the history of the development of the zone itself, which plays a relief-forming and structural rôle in the eastern section of the Tadzhik depression. Thus, for example, in so far as in the lower current of the Obihinguo River the zone is developed transverse to the course of the folding structures of the neogen age, cut by the Pleistocene leveling surface (Atlas of Tadzhikistan, 1968), one can judge as to its passiveness in this period. In relation to the activization of the tectonic movements in this region, beginning with the middle-quaternary time, the reconstruction of the river network began--formation of the cross,northwest young section of the Obikhingou River (Nikonov, 1971; Chadiya, 1971) and deformation of the leveling surfaces which were also determined, in our opinion, by the "revival" of the Khinguo-Vanch zone of breakup. In relation to the fact that on its direct continuation to the southeast the lineament corresponds according to geophysical data to the plutonic fault, it can, based on these data, be hypothesized that also on the section already assimilated by the large river (the most reliable sign of the weakened zone) it also has deep penetration into the earth's crust-- and from here, has a lengthy development and is the ancient "rejuvenated" fault.

#### Results of the Studies of TVI of Yakutiya

The TVI of the territory of northern and central Yakutiya, taken on June 6, 7, and 17, 1970 from the 4th AES "Meteor" were assembled into teleschemes (area 2880 thous. km<sup>2</sup>); they encompassed the territory in latitudinal natural zones--artic tundra, forest tundra and forest of the temperate zone, disrupted by the vertical zone of the Verkhoyan ridge and the Yano-Oymyakon upland (fig. 1, II-IV; fig. 2).

The main interpretation sign of the relief is the indirect sign--the snow cover and its uneven occurrence during the spring thawing. Thanks to this circumstance, in



the mountains with relative breakup of the relief  $\geq 300-600$  m the snow cover indicates watershed spaces, upper and middle sections of the slopes of river valleys--that is the systematic configuration of the actual valleys. In the regions of the melting snow cover (plains and low mountains) the earth's surface is expressed by a monotone dark grey tone, on whose background it is not possible to distinguish any contours. Exceptions are: the valley of the Lena River, distinguished by a noticeable darkening of the tone above the mouth of the Aldan River roughly to Zhigansk; lakes covered with ice, and thermokarstic hollows--alasses with preserved snow cover (valley of Lena River, Abyysk lowland). Thanks to the uneven occurrence of the snow cover a large number of rivers are distinguished in the Verkhoyan ridge (fig. 1, VI-III) with lateral tributaries. In the recognition of the river valleys on the topographical map numerous depressions are found in the axial section of the ridge; in the illustration of their image they are similar to the current river valleys.

As a result of the morphostructural analysis of the illustration of the river network and other features of the relief structure (large and local benches in the limits of the Lena River valley and on the southern slope of the Verkhoyan ridge, (fig. 1, I)) a complex network of lineaments was revealed (fig. 2). As already noted previously, the tectonic dependence of lineaments was established with consideration for the local features of the structure of geological forms and with the use of a series of methods of morphostructural analysis in each specific case. The greatest number of lineaments is confined to the Verkhoyan ridge and the Sette-Daban ridge. Their orientation is primarily longitudinal. However, transverse lineaments are also distinguished here. According to geological data there are no transverse structures here. Of the lineaments found by space photographs about 50% coincide with the faulting structures established by geological and geophysical studies (according to the data of maps of comparable scales) either for the entire distance or on individual sections. The remaining number of lineaments are unknown.

The majority of them are confined to the less studied and not easily accessible 123 sections of the axial portion of the Verkhoyan ridge on its eastern slope. In their interpretation signs they are also clearly expressed, and sometimes even more in comparison with the established, consequently, they can also correspond to the faults and their zones of breakup. Such lineaments, whose correspondence to the zones of breakup of faults has been established primarily by indirect structural-geomorphological data, include: Siyetindzhe-Omoloy (fig. 2 and No. 17) (divides the accumulative quaternary surfaces of the Omoloy River valley from the denudation-neogen flat-top monadnocks of the southern portion of the Kharaulakh ridge), Lenisk

(fig. 2, No. 21, 22, part No. 18; separates the accumulative quaternary surfaces of the leftbank from the denudation neogens of the Kitchansk ledge); the latter is proposed by V. V. Zabalyev (1962) according to analysis of the systematic configuration of the Lena River.

Among them the most clearly expressed is the Central-Verkhoyan lineament (fig. 2, No. 3, No. 5). According to a set of data from analysis of the relief and geological structure we tentatively classified it with the large fault disorder which plays an essential role in the formation of the relief of the Verkhoyan ridge and its eastern slope. The Central-Verkhoyan lineament is about 650 km long. It extends from the southern end of the Tuora-Sis ridge in the form of two adjacent lineaments along the watershed of the rivers Khara-Ulakh and Beris, Ebitiyem, Chubukulakh into the ridge Orulgan, determining here the longitudinal direction of the very headwaters of the transverse rivers (Dzhordzhan, Bytantay, Sobopol, Menkere). In the basin of the headwaters of the Megen River, the lineament is developed on its eastern slope, has already a southeast direction in the headwaters of the rivers Bytantay, Echiy and Dulgalakh and fades in the latitudinal branch of the Verkhoyan ridge in the basin of the rivers Dzhelinda and Kele (right tributaries of the Aldan River).

The lineament is an important relief-forming border, despite the fact that it is confined to the axial section of the Verkhoyan ridge. The main, dominant summits remain to the west of it, thereby it separates the region distinguished by the greatest depth and thickness of the erosion breakup, governed by the development of more intensive, newest tectonic movements, from the region of less intensive breakup (on the east) (Baranova, 1967). In addition, as follows from the analysis "Maps of the Leveling Surfaces and Weathering Crusts" (M. 1:2,500,000, 1971) the Central-Verkhoyan lineament clearly divides the territory with the development of various types of neogen denudation leveling surfaces, and on some sections one can also trace their deformation. The lineament is also accompanied throughout its entire length by a series of appendage, smaller lineaments, that is evidently is accompanied by a zone of breakup. The features of the lineament structure--its length, clarity of interpretation signs, features of the structure of the erosion relief and various types and deformation of the leveling surfaces, the presence of the zone of breakup and the complexity of its structure permit it to be classified with the large, newest linear morphostructure.

## Conclusions

1. For geomorphological purposes it is most favorable to use TVI from the 1-10 AES "Meteor", obtained in the winter-spring season for studying the mountain regions (primarily for structural-geomorphological purposes). The multizonal images from the 18th AES "Meteor" can be used both in the winter and in the summer season depending on the spectral channel of photography, the natural zone and the interpretation signs of the relief (in order to study both the morphostructure and morphosculpture). The TVI from the "Meteor", characterized by various resolutions on the site, have a definite, inherent only to them, level of generalization of the earth's surface and permit one to obtain information about the relief and the plutonic structure of the earth's crust not provided by other space images. /124

2. On the TVI large forms of the relief and river valleys are expressed through the totality of optical properties of their indicators. Comparative analysis of the interpretation signs of the natural targets on the different-scale images permits one to hypothesize that the intensity of certain natural targets appears beginning from a specific level of generalization of the space images--with their resolution 1.5-6 km. Extrapolation of the interpretation signs of the natural targets on small-scale TVI apparently is not possible in light of the reflection on their vast territories and therefore the unavailable analogues.

3. Television images obtained from the AES "Meteor" and "Kosmos" contain information: on the irregular nature of the water turbidity, on the ancient re-deepened valleys, on the systematic configuration of the river valleys and the features of their structure, on certain laws governing the structure of major features of the relief, on large linear morphostructures and on circular formations. Experiment has proved the advantage of TVI over aerial photographs in the study of large lineaments accompanied by a zone of fracturing to 5-7 km wide.

4. The possibilities of morphostructural analysis are still not sufficiently used in geological-geomorphological interpretation of space images. With the help of traditional approaches of morphostructural analysis one can objectively interpret the lineaments on the relief-forming linear morphostructures corresponding to the zones of breakup of faults, and related to planetary fracturing. According to the deformations of geomorphological levels, the nature of the erosion breakup and other signs, one can detect the lineaments corresponding to the fault disorders not expressed in the geological structure of the upper sedimentary layer but playing an

important relief-forming and structural role.

5. As a result of the morphostructural analysis of the TVI from various territories of the USSR, linear morphostructures of different classes were isolated. According to the complex of geomorphological and geophysical signs a correspondence is proposed for the larger of them to the zones of breakup of crusted faults (Khingou-Vanch, Central-Verkhoyan "Lena lineaments") classified with the neo-tectonic, small-amplitude fault, flexure-fault, "incipient" and "revived", rejuvenated in the latest time, ancient faults.

6. The obtained results of structural-geomorphological interpretation permit one to fully supplement and in certain cases raise the question of the review of composed ideas, of the peculiarities in the development of certain river valleys (in particular, on the origin of antecedent nature of downcutting of rivers-- Obikhingou and others, which evidently is more associated with the confinement of these rivers to the zones of breakup of folding structures cutting across the course) and large features of the relief, of the structure of the earth's crust, tectonic and seismic zoning of fairly well studied regions (in the northeast section of the Tadzhik depression); permit one to obtain new information on the not easily accessible territories (Verkhoyan ridge); in the final analysis, have great importance for directed searches for different mineral resources.

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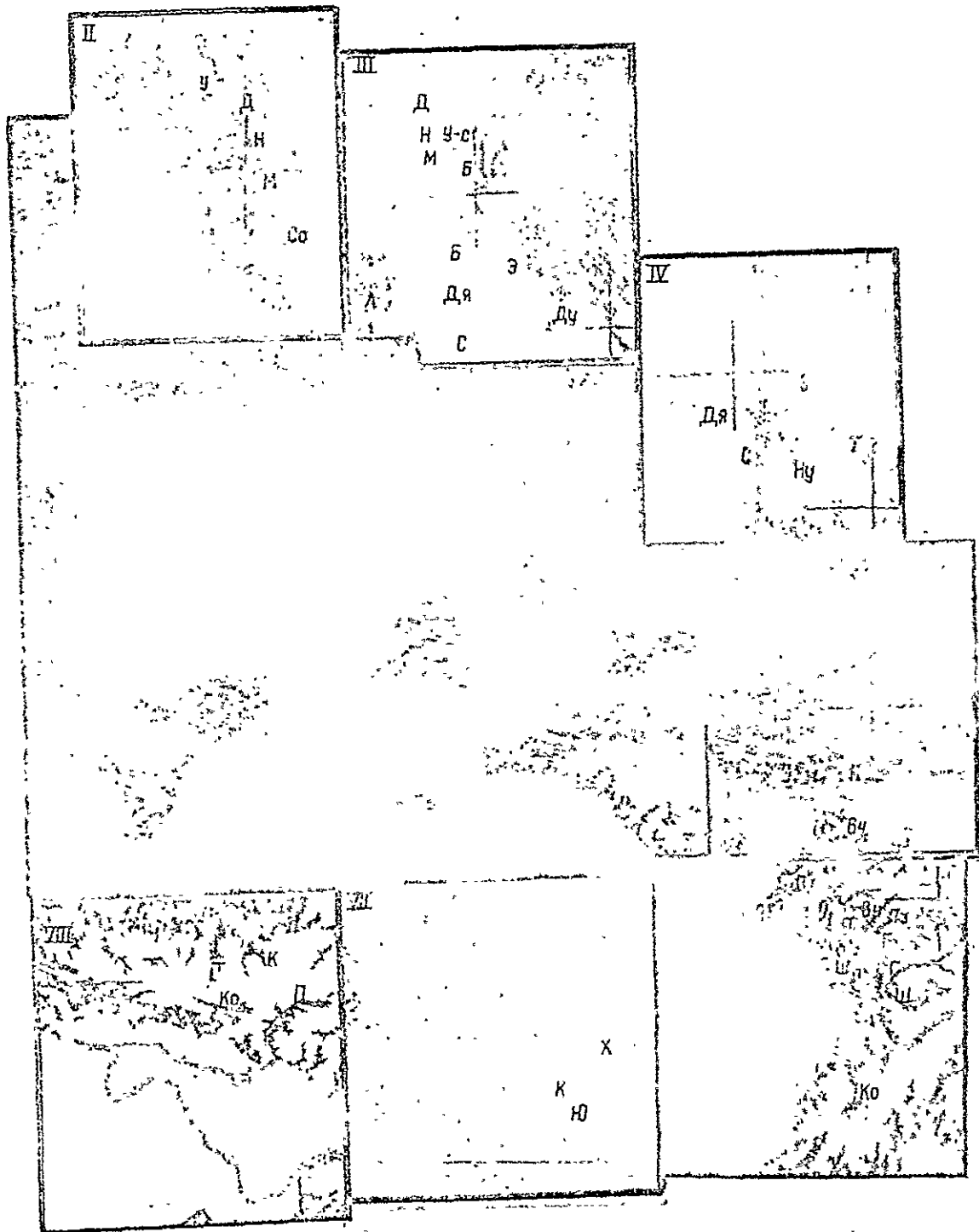


Fig. 1. Types of illustrations of river valleys on telephoto images obtained from the AES "Meteor" and "Kosmos". I--10th AES "Meteor", 10/14/1972. A--Amudar'ya, C--Syrdar'ya (given section see fig. 1, IV), а--ancient bed of Syrdar'ya-Zhanadar'ya--meandering type of valley with primarily wandering meanders. Original scale M. 1:10,000,000. II, III, IV--4th AES "Meteor", images of central part of Verkhoyan ridge obtained June 6, 7, 17, 1972 respectively. Due to re-photography one can study the dynamics of the spring decent of the snow cover, and

(continuation of legend for Fig. 1)

depending on the unevenness of its occurrence--the illustration of the river network. Joint study of the images for June 7 and 17 supplement the information on the river valleys; II - River Lena, B - River Bytantay and their tributaries with feather illustration governed by cross faults, Y - Unguotakh, II - Dzhordzhan, H - Nelan, M - Menkere, Co - Sobopol, III - Dyanyshka, C - Sagandzha, Y-C - Ulakhan-Sakyr'yr, D - Echiy; IV - Lulgalakh, Hy - Nuora, T - Tuora; with latticed illustration of headwaters-- rivers Dzhordzhan, Nelan, Menkere, Sobopol, Echiy governed by their laying along the system of longitudinal faults complicating the axial section of the Verkhoyan' ridge and for the first time isolated on the basis of analysis of the illustration of these rivers (see fig. 3, 4). V - "Kosmos-226", 9/3/1968, North Tyan'-Shan', Fergan. hollow, southern Tyan'-Shan', North Pamir (East hidden under clouds). Main rivers: K - Kyzylsu, C - Surkhob, O - Obikhingou, B - Vakhsh, B - Vanch, III - Pyandzh have irregular illustration, are laid along the zones of breakup of plutonic faults, rivers O - Obimazar, R - Yakhsu--parallel-confined to Tadzhik depression are ancient re-deepened valleys and as a consequence of this are expressed with clear interpretation signs. VI - 8th AES "Meteor" 5/7/1971. South Tyan'-Shan', Pamir, Gindukush, rivers the same as on section V, their tributaries and rivers: II - Dubursa, II - Yagnob, III - Yazgulem, B - Bartang, II - Gunt, III - Shakh dara, III - Shiva, Ko - Koncha, Ky - Kunar have feathered illustration (Yagnob River, Lubursa River) latticed, governed by longitudinal faults of Zeravshan' ridge. According to fall image--V - Pamiro-Alaya, can study only large river valleys with clear interpretation signs, according to spring--VI--both large and small, but the first with less clear signs. VII - "Kosmos-226", 9/24/1968. Desert Takla-Makan, rivers: K - Karakash, K - Yurkhta, X - Khotan, meandering in friable quaternary deposits. VIII - 8th AES "Meteor", 5/1/1971. Large Caucasus ridge, feathered illustration of rivers in basin of rivers K - Kubani, T - Teberdy, VI - Inguri, Ko - Kodor.

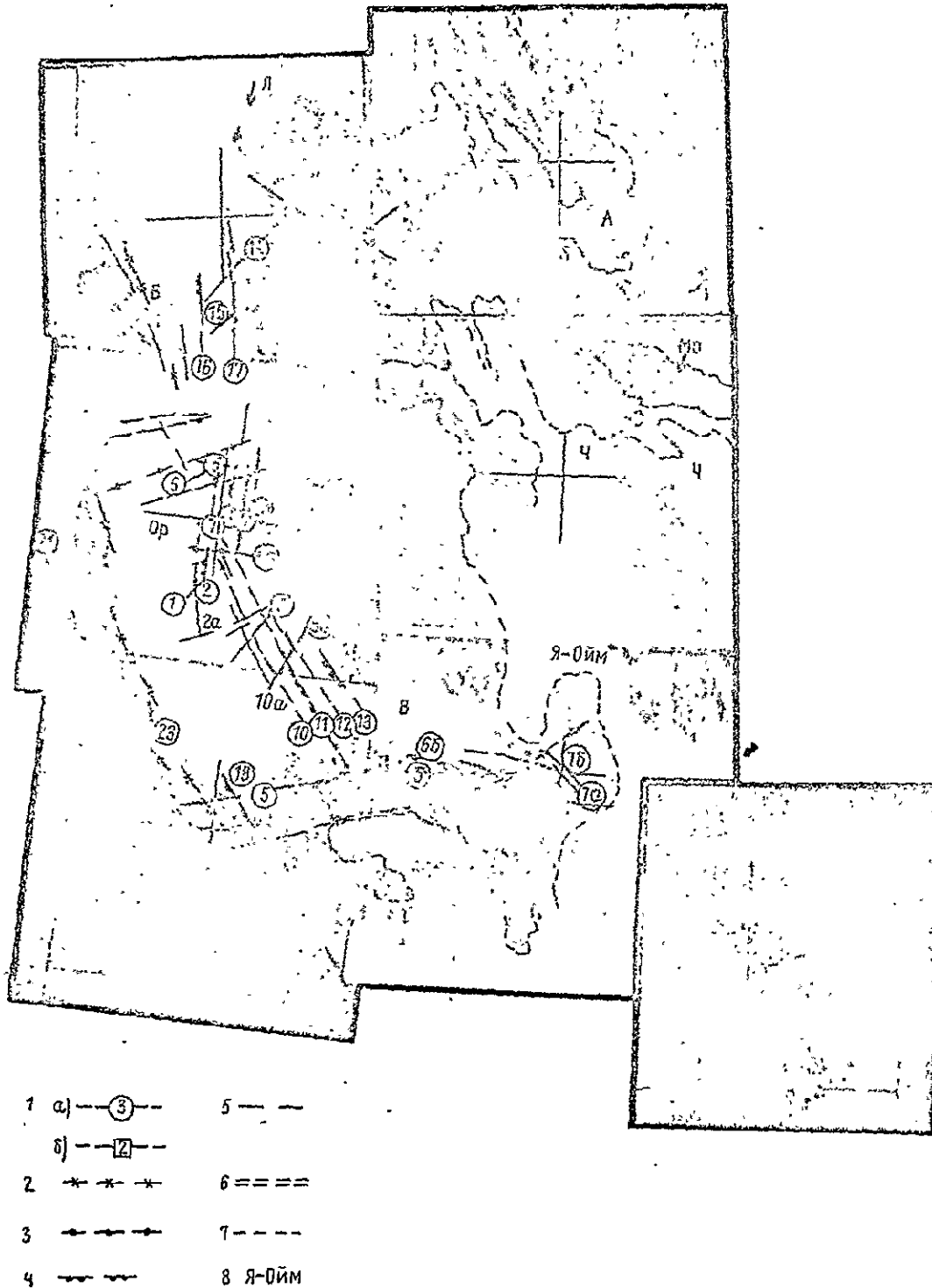


Fig. 2. Scheme of structural-geomorphological interpretation of montage of telephoto images of Verkhoyan ridge (4th AES "Meteor" 6/7/1970), on section of telephoto image of central portion of Verkhoyan: ridge-basin of Lynyshka River (4th AES "Meteor") (6/17/1970) (see similar images fig. 2, II, III, IV).

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Lineaments:

1--with clear interpretation signs:

a) "Meteor" 7/7/1970; б) "Meteor" 6/17/1970.

Note: with identical signs and numerical designations of the breakup zone see fig. 4;

2--the same, unidentified on topographical map;

3--with weak interpretation signs;

4--confirmed by geological studies;

5--Central-Verkhoyan Lineament (on section);

6--Lena River;

7--borders of cloud cover and large forms of relief;

8--geographical names: Я--Oym-Yano-Oymykon upland, Л--shore of Arctic Ocean, А--Alazey plateau, АС--Abyysk lowland; Ож--Ozhigin swell, Мо--Momsk ridge, Ч--Chersk ridge, М-С--Momo-Selenyakh hollow, Оп--Orulgan ridge. В--Verkhoyan ridge.

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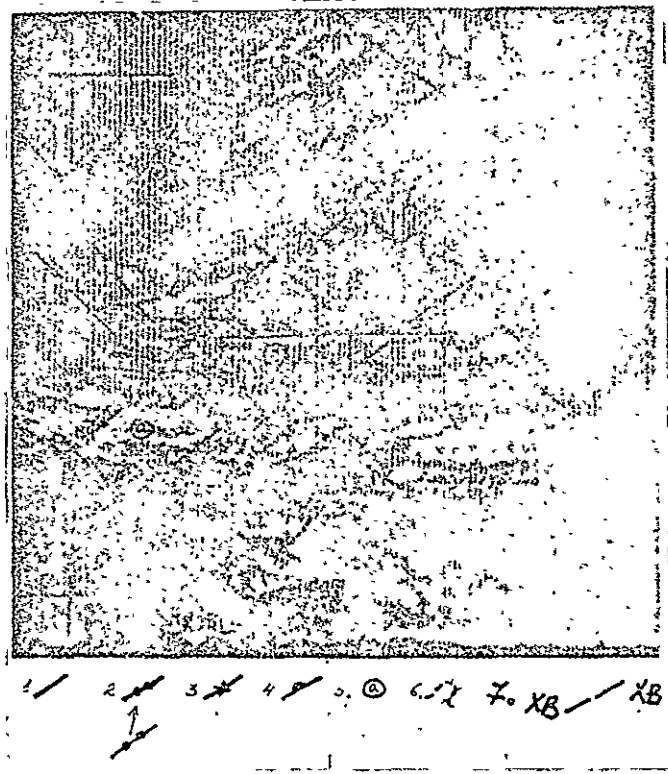


Fig. 3. Scheme of structural-geomorphological interpretation of television image of Central Asia from AES "Kosmos-226" (M. 1:3,700,000) (see fig. 2, V). 1--lineaments with clear interpretation signs; 2-- the same, with weak interpretation signs; 3--the same, unidentified or approximately placed on topographical map; 4--the same, confirmed by ground, geological, geophysical, structural-geomorphological studies; 5--a) inner and outer mountain regions with relic relief and young erosion and Alpine relief (west, south Tyan'-Shan', North Pamir). b) piedmont zones with arid-denudation relief (Fergan hollow); c) foot-of-mountain zones with arid and accumulative relief and irrigated agriculture. 6--borders of zones of geomorphological vertical zonality; 7--large, linear morphostructures corresponding to the plutonic faults; IK--Gissaro-Kokshaal, BT--Vanch-Tanymas, XIII--Khingou; large lineaments corresponding to zones of tectonic breakup: XB--Khingou-Vanch, MU--Matchin, BX--Verkhnematchin.

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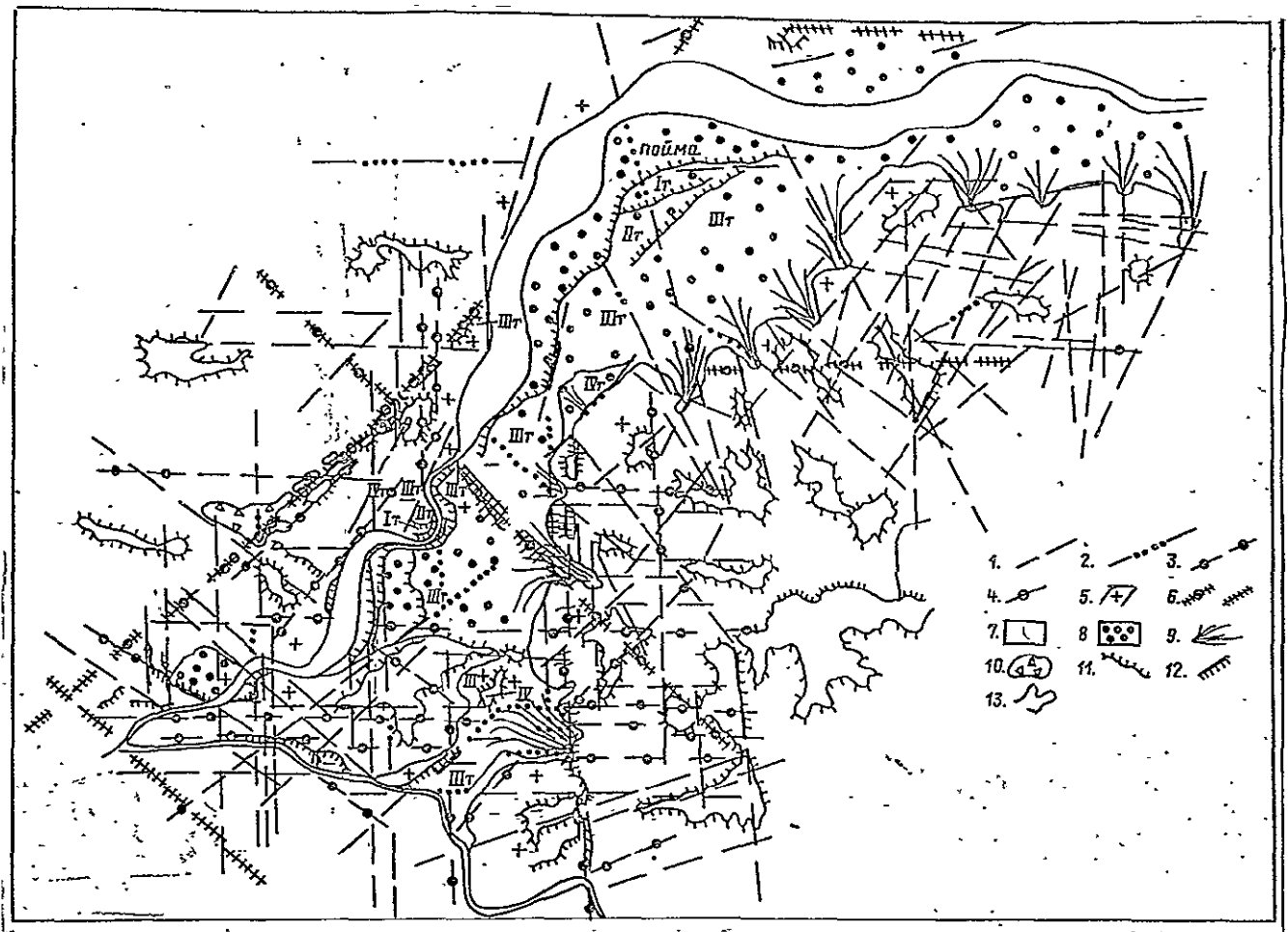


Fig. 4. Map-schematic diagram of lineaments in lower parts of rivers Surkhob and Obikhingou, compiled according to data of interpretation of aerial photographs. 1--lineaments with clear interpretation signs; 2--the same, with weak signs; 3--lineaments with clear signs, relief-forming; 4--the same, confirmed by geological data; 5--interpreted newest local blocks established according to data of profiling of river benches and analysis of the altitude fields (according to D. S. Asoyan and Ye. A. Fin'ko) (with sign +--positive shifts, with sign - (minus) negative). 6--conditional position of borders for zone of breakup, detected by space television images.

Types of relief: 7--erosion-denudation; 8--accumulative; 9--large debris cone; 10--hollows; 11--erosion-denudation ledges; 12--the same, tectonically governed; 13--borders of relief types; 14--alluvial, above-flood-plain benches (1--first, etc.).

S. Yu. Antonova and V. I. Kravtsova

Remote studies of the natural environment in recent years have been characterized by multizonal photography with airplane-laboratories of the USA (1969-1974) and the USSR (1972-1974) of the spacecrafts Apollo-9 (1969), Soyuz-12 and 13 (1973, 1974), resource satellite ERTS (1972-1973), orbital station Skylab (1973). Work is being actively conducted with multizonal photographs and instrumental methods of their processing are being developed.

By the present time, mainly on the basis of visual interpretation of multizonal photographs, it has been revealed that multizonal photography improves the interpretability of the photographs and produces a supplementary effect not everywhere, not for all targets of the photography, but only for a comparatively limited circle of them. It is very important, in our opinion, to reveal those branches of research and those natural or economic targets for which its use is the most expedient.

We were able to analyze photographs obtained in the first Soviet experiment on multizonal photography from space conducted on the space ship Soyuz-12 in September, 1973 by the USSR astronauts, Heroes of the Soviet Union V. G. Lazarev and O. N. Makarov (the experiment was conducted with the participation of the IKI AN SSSR and MGU) (Institute of Space Research of USSR Academy of Sciences and Moscow State University).

The photography, conducted for the greater part of territory in 6 zones, whose maximums of spectral sensitivity are shown in table 1, was essentially used as four-zone photography (in light of the closeness of the spectral sensitivity of 2,3 and 6 zones) in the blue (0.47 mcm), green (0.54 mcm), orange (0.58 mcm) and red (0.66 mcm) zones of the spectrum.

The experimental work with multizonal space photographs from the spacecraft "Soyuz-12" shows that one of the regions of its effective use can be the study of salinization of a territory. The targets, related to the increased content of salts, soils salinized to a varying degree and saline crusts on the surface, are characterized on the photographs made in different spectral ranges by supplemental interpretation signs. Sections of saline soils and sors in arid regions are often

TABLE 1

## WAVELENGTHS OF MAXIMUMS OF SPECTRAL SENSITIVITY FOR MULTIZONAL PHOTOGRAPHS FROM SPACECRAFT "SOYUZ-12"

Film	No. of zone	Maximum of spectral sensitivity, mcm.
Type-17	1	0.58
	2	0.66
	3	0.68
KN-3	4	0.47
	5	0.54
	6	0.64

combined with sandy areas. Light contours of sands and saline soils are weakly distinguished on ordinary space photographs made in one broad spectral range. They 132 are equally poorly separated on photographs made in the red section of the spectrum (zone 2) in the majority of remaining targets which are the most optimal for interpretation. Analysis of their image on the photographs of the blue zone (zone 4), at the first glance, of the low-expressive and least informative, indicates that in this zone the named targets are successfully divided. The contrast in the image of the majority of targets, including also sands, falls on these photographs, while the image of the salt crusts does not lose its intensity and they are distinguished by the lightest spots. This effect is observed on the photographs of various regions. We will illustrate the use of multizonal photographs for studying the salinization of a territory in the example of interpretation of photographs from the Buzachi peninsula on the northeast coast of the Caspian Sea.

In the nature of the relief the Buzachi peninsula is a flat, in places hilly, plain, whose overall monotony is complicated by several vast and many small inland-drainage machines. Here, under conditions of a dry climate, when the evaporation rate exceeds the amount of fallen atmospheric precipitation the development of saline soil processes is observed under the influence of mineralized subsoil waters. An especially considerable accumulation of easily-soluble salts occurs in the depressions of the relief where the salinized subsoil waters are located not far from the surface.

On the whole the territory is characterized by a strong degree of salinization of the soil-forming rocks. Salinization is especially great in the coastal sections of the peninsula and the territory of large sors in its northwest section. The content of salts per 100 g of dry rock here is from 2 to 12%. The majority of the territory has salinization from 1 to 2%, and only the areas of sand of Kyzylkum and Uvakhkum are distinguished by a very weak degree of salinization of the soil-forming rocks, from 0.01 to 0.5%.

For saline soils the dominant type of salinization is chloride-sodium, whereby for the peripheral sections-chloride-sulfate-sodium. For the remaining area of the territory sulfate-calcium salinization is typical (D. D. Vyshivkin, 1959, 1970).

Light spots of salinized territories of saline soils and alkali soils are clearly seen on the photographs in the 1, 2, 3, and 6 zones. Most of all the tone differences which reflect the varying degree of salinization can be distinguished in the 2 (red) zone. The following general law is traced: the lighter the zone of the image the greater the degree of salinization. Sections where the surface is covered with crusty salt are depicted as light grey, almost white.

In the interpretation of the photographs made in the 2, red zone (fig. 1) one can separate three degrees of salinization: 1) very strong salinization, sections with salt crust on surface (very light grey, almost white tone of image); 2) strong salinization (light grey tone of image); 3) not very strong salinization (grey tone of image).

On photographs in the 4, blue zone (fig. 1) the image is considerably less contrasting, therefore it is difficult to make an exact illustration of the contours (on the schematic diagram of interpretation they are shown by a dotted line). The sections where the salt emerges on the surface of the soil, the same as in other zones, are distinguished by the lightest tone. But in comparison with the photographs in the 1, 2, 3, 6 zones the number of these light sections with salt emerging on the surface here is considerably smaller, therefore on the schematic diagram compiled according to the photograph in the 4 zone a portion of those sections were not expressed which in the 2 zone and in all other zones were distinguished by the lightest tone. This indicates that in all zones except the fourth, the same light grey, almost white tone depicts the qualitatively different targets which can be differentiated only by joint analysis with the photograph in the fourth (blue) zone. A comparison of the photographs with the topographical and topical maps revealed that sections which preserve the light tone of the image in all six zones are actually salt emerging on the surface, while the sections having a light tone of the image on photographs in the red, orange and green zone, but lacking it in the blue zone, are sections of unanchored, light barkhan sands which in this zone lose their intensity and merge with the surrounding background. The final result of the interpretation using all the zonal images is presented in fig. 2.

The accuracy of the conclusions obtained during visual interpretation of the photographs also was confirmed by the results of instrumental treatment of the

negatives. Fig. 3 presents registrograms\* obtained from microphotometering the negatives for the profile passing through very strongly salinized sections encompassing also weakly salinized territories with sands.

Strongly salinized sections are characterized by greater optical density on the negatives (i.e., higher position of the curve) in all the zones. On this curve sharp peaks distinguish the sections where the salt emerges to the surface. The part of the registrogram which corresponds to the regions occupied by loose barkhan sands has in the 1, 2, 3, 6 zones the maximum values of densities, while in the 4 zone the curve drops sharply--the optical density decreases. This permits differentiation of the sands from the salinization directly from the compilation of the curves. Weakly salinized sections have less optical density in all the zones and for them the curve is characterized by a small amplitude of fluctuations which is determined by the fine-grained structure of the image.

To sum up the conducted research, taking into consideration the results of visual and well as of instrumental interpretation, the following laws were detected to govern the image of the examined targets on multizonal space photographs, which can be considered their additional interpretation signs:

1. Sections of very strong salinization have a light image tone in five zones of photography, but are depicted slightly darker in the fourth (blue) zone. They are mainly confined to the depressions in the relief, and to the sections of the peninsula which recently emerged from under sea level. They have a uniform structure of the image. On the registrogram of microphotometering in all zones they have the same great density of the image (with the exception only of that target such as loose sands in the red zone).

2. Sands emerging to the surface, as a rule, are located on sections of very strong salinization and are characterized by the same signs. The image tone on the photographs in all the zones is even lighter, almost white. The registrogram depicts them in the form of peaks of rather large amplitude above the overall image of strongly salinized territories.

3. Regions of the spread of loose barkhan sands are distinguished by the lightest tone of the image in the 1, 2, 3 and 6 zones. Their image gets a little

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\* Microphotometering was conducted in the IKI AN SSSR by V. V. Kiselev.





dimmer in the fifth (green) zone and looks considerably darker in the fourth (blue) zone, approaching in tone to the image of the unsalinized territories. The image of sands in the 1, 2, 3, 6 zones is close to the image of the sands emerging on the surface, but, by using the fourth zone they can be easily separated. The image of the salt crust in this zone remains light, the image of the sand becomes darker. A reduction in the optical density on the negative in the fourth zone is reflected well on the registrogram.

The results of the complete visual interpretation, confirmed by instrumental verification, were compared with the map of salinization of soil-forming rocks compiled by VAGT (All-Union Aerogeological Trust) by indication interpretation of geobotanical maps. In order to ensure the possibility of such a comparison, the photograph was preliminarily rectified on a FTB photoconverter.

In the comparison of the map of salinization of soil-forming rocks with the photograph we attempted to find how clearly on the photograph those numerous gradations in salinization are traced which are isolated on the map (they number 12, whereby 5 of them occur in the studied section), and on the other hand, to evaluate the accuracy of the mapping illustration by checking its photo image. The results of the analysis permitted us to draw the following conclusions:

1. Nearly all the contours on the map can be recognized on the photograph. 134  
An exception is the borders of territories on which the degree of salinization of soil-forming rocks is very small, to 1% salt per 100 g of dry rock.

2. Although on the photograph one can recognize nearly all the contours which are on the map, it is not possible to determine according to the photograph tone the degree of salinization with that fractionization that the map gives. Instead of 12 gradations shown on the map, one can only isolate three on the photograph with sufficient assurance: a) sections of strong salinization with salt crust on surface, corresponding on the map to the territory with salinization over 2%; b) sections of strong salinization without salt crusts, corresponding also to sections with salinization over 2% (these are two gradations which are not separated on the map which can be isolated with the use of photographs); c) sections of not very strong salinization, corresponding to the territories with a salt content in the soil-forming rocks to 2%. Sometimes transitional sections can also be distinguished.

3. Qualitative differences in the nature of salinization (chloride, chloride-

sulfate, sulfate salinization) are not interpreted visually.

4. The borders of contours which are unambiguously interpreted on the photograph and on the map, partially do not coincide, which is most likely governed by the inaccuracy of the map for whose compilation a rather old basis was used. Due to the poor accessibility of the territory for field routes, the deficiency of exact reference points for surveying on the site and the impossibility of using aerial photographs for compiling the map for enormous territories, these errors in making the contours are completely natural. The presence of a photographic base, close in scale to the compiled map, permits illustration of the contours significantly more accurately.

Interpretation of the salinization of the Buzachi peninsula according to multizonal space photographs permitted improvement of the map of salinization of soil-forming rocks (fig. 4). Basically, the changes concerned borders of strongly salinized territories in so far as they were depicted in more detail on the photographs. The regions with a weak degree of salinization remained almost without changes since the photographs in these zones did not permit determination of the degree of salinization if it is less than 1% salt per 100 g of dry rock.

To the number of separated gradations of salinization on the improved map has been added the category referring to sections of the territory on which the salt emerges to the surface. In addition, the interpreted image permitted us to show on the re-compiled map the borders of contours in more detail than previously.

The conducted analysis indicates that multizonal space photographs are good material for studying salinized territories and can be used for mapping salinization in several aspects: 1) for pinpointing the borders of sections with different salinization of the soil-forming rocks; 2) for revealing the sections of stronger salinization with salt crusts on the surface; 3) for separating sections of the spread of loose sands from saline soils. These targets, which have close interpretation signs and are separated on ordinary photographs with difficulty, are successfully differentiated by simultaneous use of multizonal photographs, and precisely with the combination of 4 (blue) and 2 (red) zones with maximums of spectral sensitivity 0.47 and 0.66  $\mu\text{m}$ .

Analysis of the multizonal photographs from the spacecraft "Soyuz-12" of territories with different natural and crop landscapes and water landing areas of

varying type showed that their use is effective in studying other natural targets also, shoal water landing area, sowings of different agricultural crops, forms of land use, sand deposits of varying thickness, forest fires.

Thus, a certain number of targets are revealed, a comparatively small number, for whose study the multizonal photography is effective already during visual work with the photographs.

The immediate tasks in the region of using multizonal photography consist, in our opinion, of the following:

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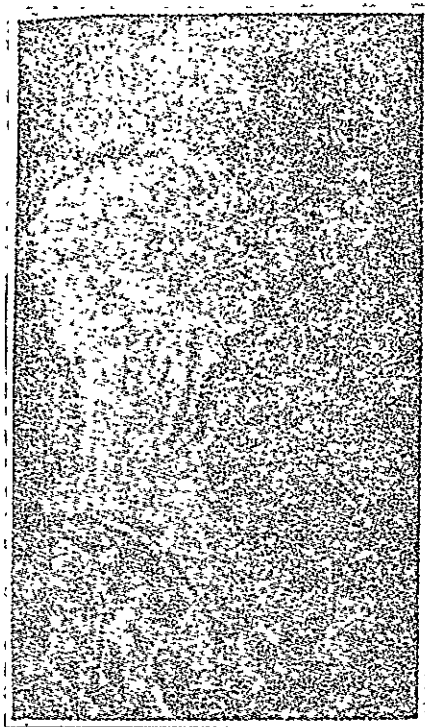
1. Further pinpointing of the types of natural targets for whose study the use of multizonal photography is effective.

2. Determination of the most optimal narrow spectral photographic ranges and their combinations for separating these targets.

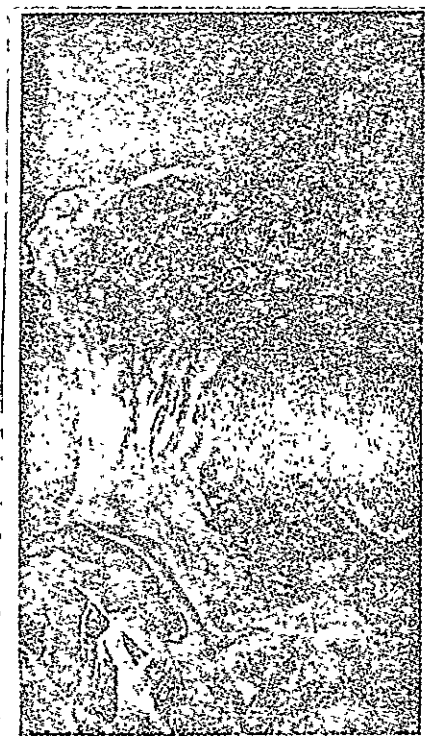
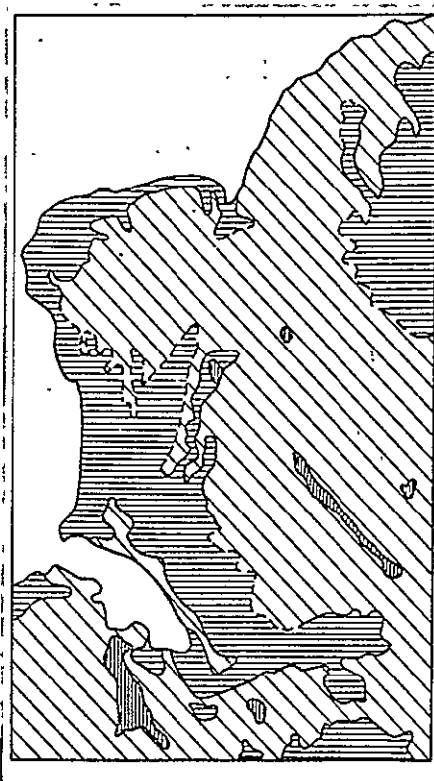
3. Obtaining multizonal photographs for various types of territories, analysis of these photographs in the example of standard territories with field provision of the study of photographed targets, including study of their spectral intensity. Analysis of multizonal photographs obtained synchronously from different altitudes in order to reveal the atmospheric effect in different zones of the spectrum, the effect of the scale of the photography, etc.

4. Development of a technique for interpreting multizonal images, visual, instrumental and finally, automated. The latter are tasks of great complexity and require the creation of special instruments and the development of algorithms, but their solution, although a partial one, is necessary.

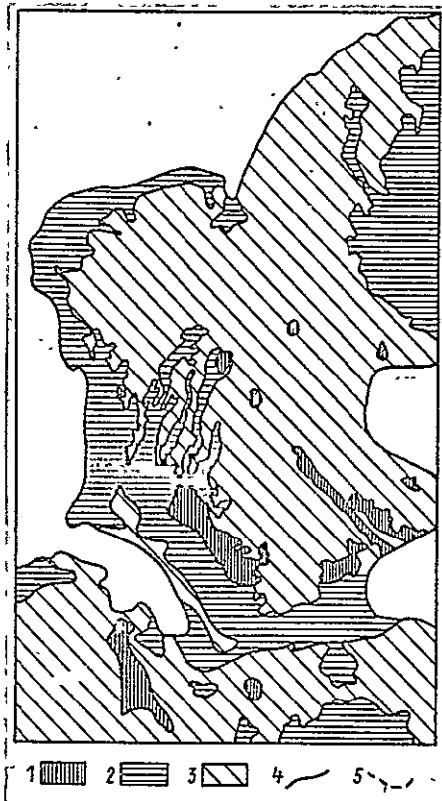
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Zone 4 max. 0.47 mcm



Zone 2 max. 0.66 mcm



1 2 3 4 5

Fig. 1. Results of interpretation of salinization of territory of western part of Buzachi peninsula according to space photographs obtained in different spectral zones: I--zone 4 (max. 0.47 mcm); II--zone 2 (max. 0.66 mcm). 1--sections of very strong salinization with salt crust on surface; 2--sections of strong salinization; 3--sections with salinization from weak to strong; 4--clearly distinguished contours; 5--not clearly distinguished contours.

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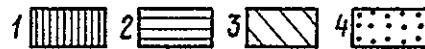
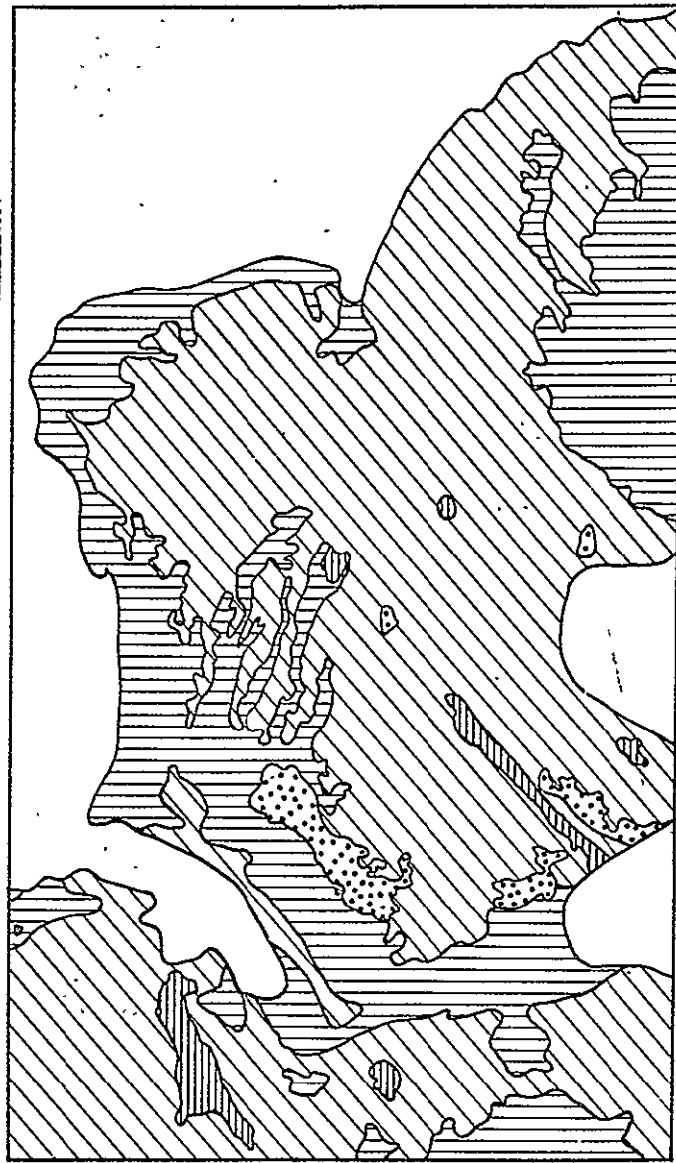


Fig. 2. Results of interpretation of salinization of territory of Buzachi peninsula with the use of photographs obtained in the fourth (max. 0.47 mcm) and second (max. 0.66 mcm) zones. 1--sections of very strong salinization with salt crust on surface; 2--sections of strong salinization; 3--sections with salinization from weak to strong; 4--sands.

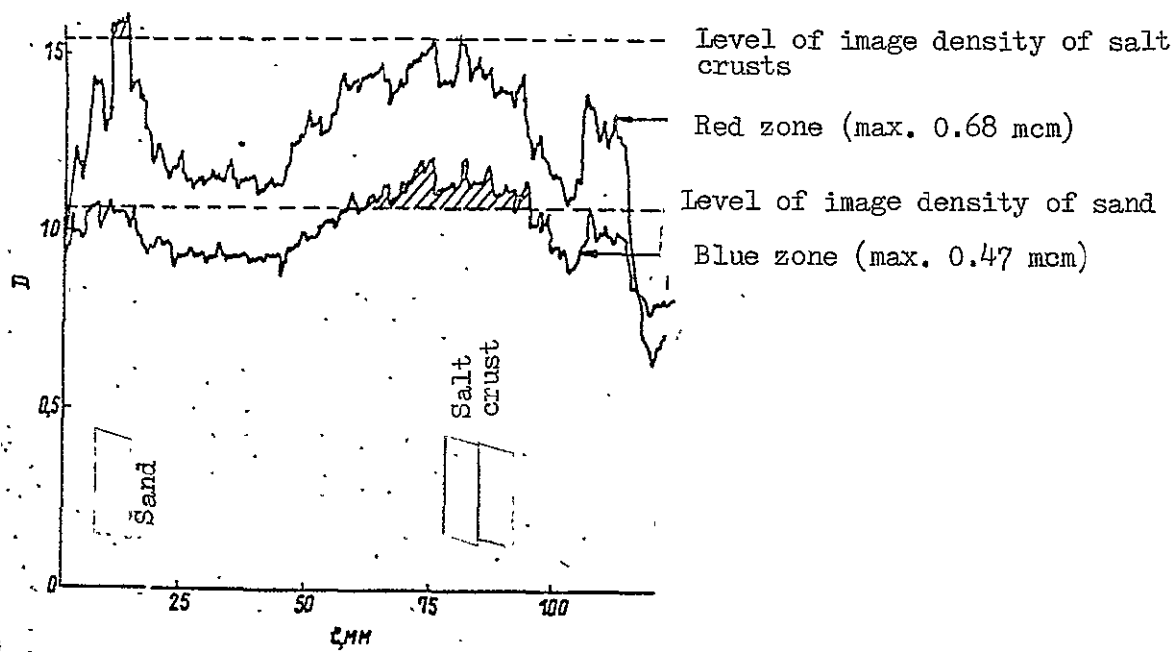


Fig. 3. Registrogram of measurement of image density for sands and saline soils on photographs taken in the blue (max. 0.47 μm) and red (max. 0.66 μm) zones of the spectrum.

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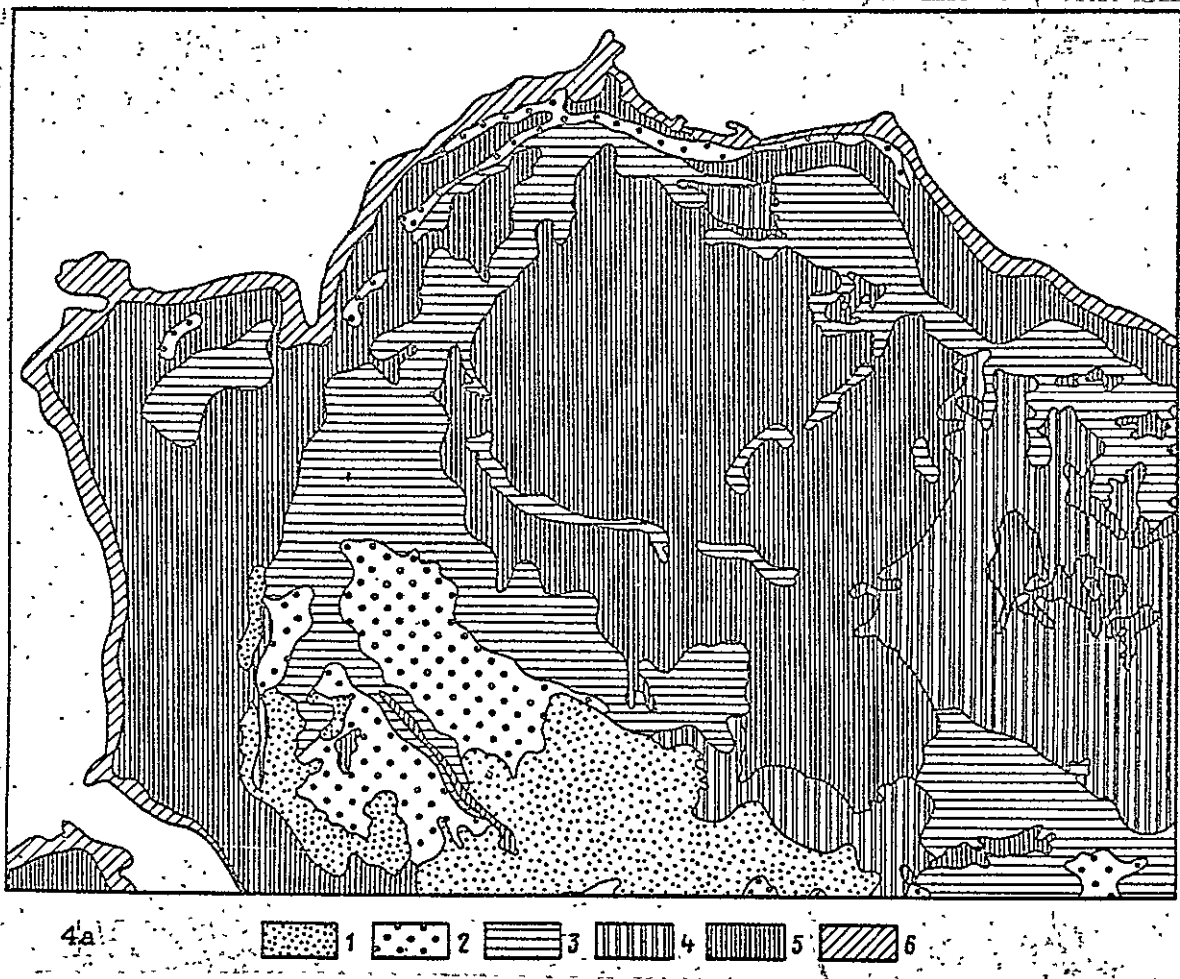
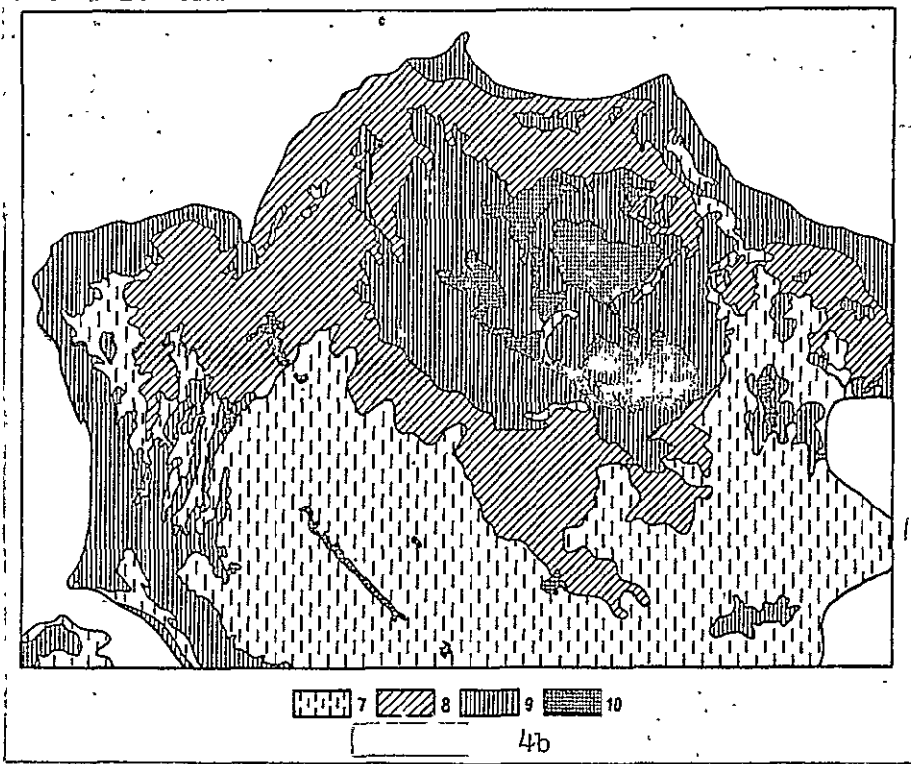


Fig. 4. Fragment of map of salinization of soil-forming rocks (I) and results of interpretation of salinization of territory of Buzachi peninsula according to multizonal photographs (II). I. Degree of salinization on map (in % per 100 g of dry rock): 1--0.01-0.25%; 2--0.26-0.5%; 3--1.01-2.0%; 4--1.01-12.0%; 5--2.01-12.0%; 6--0.25-12.0%; II. Degree of salinization revealed from photographs: 7--not very strong salinization, corresponding to the salt content less than 2%; 8--transitional type between not very strong and strong salinization, corresponding to the salt content about 2%; 9--strong salinization, corresponding to a salt content over 2%; 10--very strong salinization (sections with salt crust on surface), corresponding to salt content up to 12%.

[Translator's note: for "I" and "II" read "4a" and "4b" respectively.]

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V. L. Andronikov, M. G. Sinitsyna and G. A. Shershykova

Calculation of the structure of the soil cover and its changes in the regions of intensive agriculture is important at the current stage of development of soil-mapping work (Grigor'yev, 1970, 1973, Krupenikov et al., 1973, Fridland, 1972, 1973). The characteristics of the structure call for description not only of the composition and components of the soil cover, but also a study of their interrelationships, processes of evolution and spatial arrangement created by areas of soils (Fridland, 1972). The materials of aerospace photography, reflecting in detail the soil-vegetation cover of the earth's surface permit a comprehensive, in interrelation with other elements of the natural landscape, study of the structural features of the soil cover.

We study the soil cover in the field with the help of soil sections, i.e., individual points of the soil cover. The main advantage of the aerospace materials consists of the fact that they characterize the spatial arrangement of the soil cover. The structure of the soil cover is expressed only on the aerial and space photographs. The aerial and space photographs most clearly transmit the dimensions and shape of the targets which belong to the direct interpretation signs of the soil cover. This is very essential since the aerospace photographs permit with the greatest completeness the study of the geometry of the structures of the soil cover, their composition, complexity, contrast and nature of the borders of elementary soil areas.

Different types of mottling are rather easily established (Grigor'yev, 1970) on the plowed up territories when materials of aerial photography are available. Without the use of aerial photographs the determination of the type of mottling, calculation of the areas occupied by its individual components, and mapping of the mottlings and complexes are not very promising. Otherwise, the work becomes labor intensive and requires high monetary outlays.

In the subzone of soddy podzolic soils the nonuniformity of the soil cover on the exposed surface of plowed up spaces is recorded on the aerial photographs by the mottled illustration of the photoimage (Dolgova, 1964, Sinitsyna, 1973). This permits the more exact reflection on the maps of various forms of nonuniformity of the soil cover and calculation according to the photographs of the percentage ratio

of areas of individual components. (Fridland, 1972, in examining the question of the methods of studying the structure of the soil cover indicates that an effective method for compiling the soil profiles and maps necessary for studying the structure is the use of aerial photographs of various types and scales.) The materials of aerial photography allow easy differentiation not only of the areas of various monocombination structures of the soil cover, but also separation of the elementary soil areas in size to 10-15 meters.

In this work, on the example of the poor in chernozem zones of the RSFSR (Smolensk regions and Meshcher site (and steppe zone), Kursk and Kustanay sites, Rostov and Orenburg regions) we will examine the use of aerial photographic materials to study the structure of the soil cover. The work also uses the space photograph obtained from the American satellite "ERTS-1".

The structure of the soil cover is reflected in the texture of the photo image which is the natural combination of phototones. The study of the texture of the photo image and their classification, establishment of the correlation between them and the structure of the soil cover are necessary conditions for the reliable soil interpretation according to aerial and space photographs.

Before describing the most widespread textures of the photo image of soils, we will indicate a number of factors which affect the information content of the photographs and obtaining the most expressive (contrasting) texture of the photo image. /141

One of the first factors that should be named is the time of the photography. On the photographs of the same territory taken in the spring and summer season of one year it is apparent that the striated structure (not sharply expressed) of the slightly eroded chernozems are clearly seen on the spring photographs and are hidden under a cover of crops. On the contrary, the soddy-like texture of the meadow-chernozem soils on the background of plowed up fields in the spring period is poorly seen, while in the summer it shines through the grain sowings sharply. On the spring and summer photographs the alkaline soils and chernozems, thin and detrital, appear clearly.

For successful interpretation of the soil cover, importance is attached to the stability of the texture of the photo image on the photographs of different years of photography, in order to use previously developed signs on the standard sections for spatial interpolation and extrapolation.

Analysis of the photographs for different years but only spring of photography showed that they have a similar texture of the image which is characteristic for the soil cover in the territory of the watershed upland of the left bank of the Volga with narrow and flat summits of watershed uplands on which the southern chernozems are formed; with eroded slopes and numerous hollows in which meadow-chernozem soils develop. Alluvial soils had a similar texture, but a different tone of the photo image which is related to the difference in the spring flood of the steppe rivers in various years.

The next important circumstance for obtaining the most expressive (contrasting) texture of the photo image consists of selecting for photography the most effective zone of the electromagnetic spectrum. On the territory of the Kursk site, in spring of 1973, multizonal aerial photography occurred on black and white isopanchrome-17 film in intervals with effective wavelength 500, 520, 590, 640 and 670 nm. Analysis of the photo image of the structure of the soil cover on these aerial photographs showed that the most informative were photographs with  $\lambda_{ef.} = 640-670$  nm. Photographs obtained in the neighboring zone of 590 nm were less contrasting, with the exception of individual targets.

A study of the texture of the image of photographs in the steppe zone taken with  $\lambda_{ef.} = 590, 640$  and  $670$  nm permits one to conclude that the basic background of the soil cover in this territory, represented as typical chernozems, typical chernozems with lowered effervescence and dug-up chernozems, is depicted uniformly by a dark grey tone. The unpronounced striations and lightening of the tone in the photo image are characteristic for the slope, near-ravine sections with the presence of lightly eroded chernozems. Very markedly, especially on the photograph taken with  $\lambda_{ef.} = 640$  nm steppe ravines are noted with chernozems of lowered effervescence, chernozems with light and average erosion on slopes and meadow-chernozem soils in the ravine bottoms. The most mottled tone is characteristic for the sections of deciduous forest (mainly oak). This variegation on the one hand is related to the difference in projective cover of the surface of wood-bush vegetation; on the other hand--to the difference in the soil cover.

Aerial photographs taken in the zone  $\lambda_{ef.} = 500$  and  $520$  nm, had weak contrast and were essentially unsuitable for the work.

We will now examine a number of the most widespread tonal textures of the photo image in the soddy podzolic and chernozem zone of the European section of the USSR.

In the soddy podzolic zone where considerable areas are covered with woods, interpretation of the soil cover is made indirectly through the image of the forest vegetation. In this case, a stable sign is the grain texture. In the southern section of the forest zone this texture of the photo image is inherent to the soddy-weak, soddy-average and soddy-strong podzolic soils located under the forest. Another characteristic tonal texture of the forest-covered territories of this zone is the grainy-spotty. Its individual types can be defined as grainy round-spotty, grainy elongated-spotty and grainy lobe-spotty. These three types of textures of the photo image are characteristic, for example, for the swamped, forest-covered part of Meshchera with swamp and meadow-swamp soils. The third widespread type of texture of the photo image is the grainy linear-woody; if the first two types of texture were characteristic for the watershed, lightly broken-up section of territory in the soddy podzolic zone, then the third is typical for the slopes with varying manifestation of erosion. The grainy picture can be missing in the hydro-morphic soils confined to the hollows with grassy vegetation. /142

Different types of tonal textures in the photo image which reflect the structure of the soil cover in the soddy podzolic zone were successfully isolated according to the photographs for the territory of Smolensk-Moscow elevation and the Meshchera lowland. On the photograph are clearly seen the grainy and grainy-spotty texture of the sections corresponding to the complex combinations of soddy podzolic, swamp-podzolic and swamp soils. The aerial photographs of the territory of the Smolensk-Moscow elevation encompass two types of different soil-geomorphological regions of the gently sloping-wavy watershed composed of covering loams of 4-6 m thickness with underlying moraine.

Three types of elementary soil structures are characteristic for the most planar, lightly-hilly with pronounced closed sinks relief. The first consists of soddy podzolic soils of a varying degree of podsolization and confined to the hilly section of the plain. The second encompasses hollow depressions and planar sections of the plain. Its components are soddy podzolic, average and strong podzolic, occupying 55%, soddy-strong podzolic, surface-gleyey--30%, soddy-podzolic-gleyey--15%. The third includes small, closed sinks with peaty-gleyey and peat soils of peat moss, forest-covered swamps.

Another region of the Smolensk-Moscow elevation is characterized by a more complex, grainy and grainy-spotty texture of the photo image which corresponds to the more diverse in the natural sense soil-geographical region. The relief of the

section is low-hilly with many closed, swamped depressions. The soil cover of the hilly sections is represented by soddy-light and soddy-medium podzolic soils. On the more leveled, flat sections of the watersheds, adjacent to the hollow-forming depressions, soddy-strongly podzolic gleyey and soddy-podzolic-gleyey soils are formed. In the closed sinks and depressions between individual hills floodplain and upper swamps are located.

We will examine still another unique type of structure of the soil cover which is characteristic for the valley-outwash plain of the Meshchera lowland. This is a typical section with grainy-spotty texture, governed by the extensive development of the swamp soils. Here are represented round-elongated and lobe-spotty types of texture. The grainy linear-tree-like type of texture in the photo image is inherent to small sections. On the aerial photograph, according to the nature of the meso-relief one could distinguish hilly-ridge territories covered with lichen pine forests or heather-lichen, or flat knolls with pine-evergreen green forests. The soddy podzolic soils are podsolized to a varying degree. The second component of the territory--flat planar sections with mixed birch-pine forests and swamp-podzolic, peat-podzolic-gleyey and soddy podzolic-gleyey soils. The third--hollows with lowland swamps overgrown with black alders, with peat and peat-humus-gleyey soils. The fourth--sink-hollow swamped sections for the greater part forest-covered with upper and transitional swamps with peat thickness 0.5-2 m and over.

On the aerial photographs the tillable sections of the podzolic zone are distinguished according to the various types of spottiness and the linear-tree-like texture reflecting the structure of the soil cover in this zone. The graininess inherent to the image of the forest is missing here. Usually on the arable lands of the soddy podzolic subzone the elementary structure of the soil cover is presented as a two-three component mottling. The greater number of components is related to the presence of washed away, alluvial and cultivated to a varying degree soils. On the aerial photographs the differences between the individual components of the mottling are represented by a varying tonality.

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The reclaimed lands within the alluvial-outwash plain of the Ryazan Meshchera are located on swamped territories with chaotically dispersed sandy island monadnocks. In the soil cover here, swamp soils dominate, occupying ancient hollows of the flow, closed depressions and leveled sections of watersheds. Less widespread are soddy podzolic, automorphic and with signs of gleying, confined to sandy monadnocks. On the dried territories the combinations of the aforementioned soils determine the nature

of the soil cover, which on the aerial photographs of the spring flying (scale 1:12,000) were reflected in the shape, tone and illustration of the photo image. The soil cover of a plowed field is interpreted directly by the tone and illustration of the photo image, as well as indirectly according to the relation of the soils to the relief. These signs were used in interpreting the soil cover of the dried territories of the Meshchera site.

Large areas of dried peat, lowland soils (with elements of the transitional type) on the middle and deep peats are distinguished by a grey tone of the photo image and very unexpressive large-spotty illustration. On the basis of preliminary studies the natural links of these spots to the varying thickness of the peat were not successfully established. A very contrasting pattern on the aerial photographs is characteristic of a complex soil combination whose components are peat soils on average and fine peats, peat-gleyey, peat-humus-gleyey, soddy-podzolic gleyed, sandy and sandy loam soils. Another sharp-contrasting soil combination is represented by soddy-podzolic-gleyey and gleyey soils, peat-leyey soils and soddy-weakly podzolic soils on sands and their interpreted differences. The soil cover of the reclaimed section, located on the watershed and the gently sloping incline towards the very lightly cut hollow, differs markedly from the swamp areas in the composition of the components, shape and dimensions of the contours. On the aerial photograph this section has a contrasting, not ordered spotty illustration of the image.

The steppe zone is characterized by significant diversity of the tonal textures in the soil cover. On the aerial photographs of the watershed spaces of this zone there is rather often a round or elongated-spotty, lightly-contrasting texture. It is associated with the presence of microsinks, to which are confined meadow-chernozem, and in the zone of dry steppes, meadow-chestnut soils. Due to the increased moisture of the soils in the sinks and the great content of humus in comparison with the surrounding territories, they are depicted on the aerial photographs by dark spots. In the subzones of ordinary and southern chernozems and chestnut soils the spotty-dotted texture is widespread. The light dots correspond to the surchin on the chernozems and chestnut soils. On the territory of West Siberia the spotty texture is characteristic for solods.

On the slopes in the steppe zone the linear-tree-like texture of a light tone with subdivision into the following types is widespread: finely-striated; linear-tree-like and complex-tree-like. The division into the types is made according to the manifestation and development of the erosion soil processes on the studied

territory. As our studies showed in the steppe zone for investigation of the eroded soils with the help of aerial photographs, different stages in linear erosion, beginning with the striated washout to the formation of ravines, their closure and conversion into a gully, are very successfully interpreted on the photographs by their tone, form and dimensions, and confinement to the slope elements of the relief. On the slopes one should also isolate into an independent type the linear-tree-like texture of a dark tone. It corresponds to the image on the photographs of hollows and ravines with the meadow-chernozem, and more southern meadow-chestnut soils confined to them.

For the southern section of the steppe zone, in the regions of the appearance of alkaline soils the spotty-grainy texture is very typical for the photo image of a 144 grey or light tone. On the site it corresponds to two-three component structure of the soil cover. One should also recall the spotty structure having a light or light-grey tone of the photo image. This type has a lithogen nature of formation and local spread.

Of great scientific importance is the question of the effect of scale on the texture of the photo image. Preliminary considerations can be stated on this question on the basis of a comparison of the aerial photographs 1:100,000 and 1:40,000 scale and magnification of the latter by roughly three times to 1:12,000. On the territory of the Meshchera lowland on small-scale photographs of 1:100,000 scale sections were well interpreted of flat, poorly drained watersheds with soddy podzolic and sandy, soddy strongly podzolic gleyey, peat-gleyey soils, peat-humus-gleyey soils and territories of reclaimed lowland swamps. On aerial photographs of average and especially large scale the structure is clearly determined for the soil cover of these territories, including the elementary structure. Only on the aerial photographs of a large scale could one determine the drainage network with assurance. On the forest-covered territories reflected on the large-scale aerial photographs, the automorphic, polyhydromorphic and hydromorphic soils were distinguished according to the different nature of the forest. On the medium scale and especially on the small-scale photographs of 1:100,000 scale, where the change in types of forest was not visible, the division of automorphic and polyhydromorphic soils was difficult or impossible.

Especial importance, due to the expanding use of space materials for studying the soil cover, is attached to the study of the texture of the space photograph photo image. One of the characteristic features of the space ultra-small scale

photographs consists of the fact that significant optical generalization of the soil cover structure occurs on them. The establishment of the soil cover structure according to the texture of the space photographs is an important scientific problem of the near future. To process space photographs obtained from ERTS-1, R. Haralick, K. Shahmugan (1974) focus attention on the necessity of using the texture of the image which easily lends itself to visual assessment and with whose help one can find the objective and exact expression necessary for machine analysis. By using the textural and spectral features of the photo image the accuracy of determining the classification types of land use was revealed (coastal coniferous and deciduous forests, meadows, water, irrigated lands, city areas) which was 83%. Of great importance is the joint use of aerial photographs and photographs obtained from AES (artificial earth satellite). Space photographs (O. Kolbl, 1974) do to the small scale do not have sufficient interpretability, therefore it is promising to use in addition to them aerial photographs of 1:50,000 and 1:100,000 scale.

Our studies used a fragment of the space photograph of the Tsimlyan section obtained on June 11, 1973 in the zone 0.6-0.7 mcm from the satellite ERTS-1 on the scale 1:1,000,000 and aerial photographs of the same territory of medium scale. Comparative analysis of these materials indicated the following. On the aerial photograph of the territory of the floodplain and benches of the Don river two types of texture of the photo image are clearly seen. The first is striated-lenticular-oxbow which is characteristic for alluvial-meadow alkaline, alluvial-sandy and meadow-swamp soils. The second is spotty-grainy, typical for meadow-chnozem alkaline soils and alkaline soils, meadow-steppe. On the aerial photograph of one of the watersheds in this territory a dotted linear-soddy-like texture of the photo image is clearly interpreted. It reflects the soil cover which is represented here by southern chernozems, dug-up surchin chernozems and meadow-chnozem soils.

On the space photograph the features of the soil cover structure are not visible in the watershed section. In the generalized form the alluvial meadow soils are interpreted with assurance on it according to a darker tone; according to the light tone (with dark dots and lenticles of oxbow lakes, spots of moister irrigated sections) the contour of meadow, meadow-chnozem alkaline soils with meadow-steppe alkali soils. However, the alkaline spotty-grainy structure on it is not visible. The watershed sections on the space photographs have a very expressive texture of the image of fields occupied by different agricultural crops under which it is difficult to interpret the soil cover. According to the space photograph the varying structure is well interpreted for the irrigated and unirrigated fields. In individual cases,



the network of irrigation canals is clearly seen. Sections along the large and small rivers with alluvial meadow soils are easily determined according to the varying texture of the photo image.

Comparative analysis of the image of the soil cover structure on the aerial photograph and the space photograph showed the necessity of joint use of these materials for studying and mapping the soil cover.

## Conclusions

1. The degree of interpretability of the soil cover structure and its reflection on the aerial photographs in the form of the corresponding texture of the aerial photo image are significantly affected by the time the aerial photography occurs and the possibility of using multizonal photographs. The greatest contrast was obtained in the zone 640 nm, photographs in other zones were used as an additional source of information.

2. For the territory of the forest and steppe zone the most widespread tonal textures of the photo image were revealed. In the forest zone these are the following textures: near the forest, grainy, grainy-spotty-soddy; on the plowed field, different types of spotty and linear soddy texture. In the steppe zone, spotty-dotted, spotty-grainy; for eroded territories, fine-striated, linear-soddy and complex-soddy. The dimensions and tonality in the illustration of the texture depend on the genetic features of the soil cover structure. A correlation was made between these properties of the texture and the soil cover structure.

3. Due to the strong optical generalization, the texture in the photo image of the soil cover on the space photograph sharply differs from the texture of large-scale aerial photographs whose photo image sufficiently completely reflects the structure of the soil cover in specific natural regions.

4. For an effective, scientifically substantiated study of the soil cover structure it is necessary to have a joint use of space photographs and aerial photographic materials of various scales.

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In remote studies one of the important factors for improving the information content of the knowledge about soils and agricultural crops is the use of spectrozo-  
nal and multizonal aerial photographs.

The studies conducted on the information content of spectrozo-  
nal aerial photo-  
graphs (Andronikov, 1962, Simakova, 1967, Polyakov, 1968) for investigation of the  
soil cover indicated that they have considerable advantages in comparison with the  
panchromatic in relation to the isolation of eroded, water-logged soils and soil  
contours under the natural or crop vegetation. Under production conditions, in the  
soil photography on the territory of Kazakhstan the use of spectrozo-  
nal aerial  
photographs permitted improvement in the productivity of labor of the soil scientists  
by 30%.

In the GDR (A. Reinhold, F. Asmus, 1968a, b) special studies were made to  
investigate the information content of the volume of aerial photographs obtained  
with different variants of aerial film-light filters. This work was completed for  
the purposes of compiling large-scale soil maps 1:10,000 scale. It was established  
that the best interpretation properties in relation to the soil cover are attributed  
to aerial photographs obtained by the use of spectrozo-  
nal film SN-2M and a red  
light filter. In the degree of revealing the meadows and pasture lands the spectro-  
zo-  
nal film surpasses all the black and white films.

In the Polish People's Republic (E. Riechowicz, 1966) a comparative study was  
made of the interpretation possibilities of aerial photographs with infrared, color  
and spectrozo-  
nal film. Experiments showed that the spectrozo-  
nal aerial photographs  
increase the interpretation possibilities by 25-30% in comparison with black and white  
and color aerial photographs. In France the National Center for Space Studies  
(M. Isambert, P. Horemans, 1971, P. Leroux, 1971, M. Girard, 1971) researched the  
use of black and white panchromatic and infrachromatic, color and spectrozo-  
nal film  
for studying the soil cover and interpreting the agricultural crops. They noted  
the efficacy of agricultural interpretation of color and spectrozo-  
nal aerial photo-  
graphs for obtaining the characteristic of cultivated crops.

In Cambridge, England (T. S. Bell, 1974) for the purposes of the Ministry of  
Agriculture, aerial photographic work was conducted to study sowings, agricultural

crop diseases and the soil characteristics. For the successful interpretation of these targets by aerial photographs great importance is attached to the correct selection of film and filter combinations. Usually two cameras are used--one with panchromatic and the other with infrachromatic film. Color spectrozonal films are the best for interpreting the agricultural sowings and their diseases.

We also recall the research conducted (E. Schmidt-Kraepelin, 1959, R. Colwell, 1960; A. Kuhl, 1970; S. Parry et al., 1969) in the FRG and USA on the use of color aerial photography for studying soils involved in agricultural treatment and the state of agricultural sowings. Comparison of the color and black and white aerial photographs showed that color of the photo image can be successfully used to distinguish close differences in soils, their moisture, degree of humus content, to discern the late-summer crops, clover, root crops, to establish sections affected by agricultural pests, etc. These examples show that in order to improve the interpretability of the soil cover the aerial photography is conducted with a varying set of films and filters. In addition to this systems are more often beginning to be used which consist of several cameras with different light filters. With simultaneous photography on one film with different light filters multizonal photographs are obtained which characterize the soil-vegetation cover simultaneously in several narrow zones of the visible spectrum. In one or several cameras during this photography infrachromatic, color or spectrozonal films can be used. In this case the information content of our knowledge about the soil cover will be even greater. /148

In the USA (A. Park, 1969; G. Bylinsky, 1968) studies were described using 9 and 4 objective camera in order to obtain the image of agricultural fields. The photographs obtained with the use of this camera permit interpretation of the soil contours and the sowings which are clearly seen in one zone of the spectrum and poorly seen or not seen in others. In order to increase the contrast between different soils special filters can be used (H. Rib, R. Miles, 1969).

This work presents the results of research on the features of interpreting the soil cover of the territory of the Kursk site according to black and white photographs obtained with panchromatic, color and spectrozonal film. Photographs of large scales taken in different years and different seasons of photography are analyzed.

For the studied territory results are also presented from a comparative analysis of multizonal aerial photographs obtained by the aerial camera AFA-39 M with a set of light filters in 6 different zones of the spectrum encompassing the visible and

near infrared range of the spectrum. In the zone of wavelengths 0.35-0.7 mcm aerial film isopanchrome type 17 was used, while the near infrared zone was covered by SN-6M film taken with an OS-14 light filter cutting the region of sensitivity to the blue-green section of the visible spectrum of wavelengths. Aerial photographs of 1:40,000 scale (completed on the scale of flying) and enlarged large-scale aerial photographs were used to interpret the soils and agricultural crops.

A study of the interpretability of the soil cover and agricultural sowings of the Kursk site from these aerial photographs was conducted on control test sections which had comprehensive soil characteristics. As an example we will examine the soil-geographical conditions and the photo image of one of the sections of this territory.

The studied territory is located in the southwest section of the Central Russian elevation. The relief of this territory is characterized by the domination of flat, less often flat-convex watersheds with gently sloping long inclines. The microrelief is expressed in the form of individual, saucer-shaped microsinks; microknolls, often leveled as a result of plowing and small erosion hollows confined to the middle and lower section of the gently sloping watershed inclines. The soil-forming rocks are represented mainly by timber-like, carbonate loams having a thickness to 10 and more meters. The subsoil water is to a depth of over 10 meters. On the flat watershed sections the main background of the soil cover comprises typical chernozems with normal or reduced effervescence and carbonate, dug-up surchin chernozems. The typical chernozems have a thick humus-bed 60-80 cm of dark color with a good powdery-grainy structure. The content of humus in the upper bed is about 7%. The content of exchange cations is from 34 to 54 m-equ. per 100 g. Below the humus there is an illuvial-carbonate bed. In the variants with the normal effervescence calcium carbonates appear from a depth of 50-70 cm, in variants with lowered effervescence, the upper border of the carbonate lies at a depth of 90 cm, but more often it is located at a depth of 120-150 cm. According to their mechanical composition these soils are heavy-loam. On several higher watershed areas the percentage of typical chernozems with normal effervescence in comparison with the variants with reduced effervescence increases. On the gently sloping inclines to the ravines, in the flat ravine amphitheaters, on the contrary, the participation of typical chernozems with reduced effervescence increases. In the dug-up chernozems the humus and carbonate-illuvial beds are mixed strongly with excavations. These soils froth intensively from the surface. In the relief they are confined to small knolls often level on a plowed field. In the case where the surface of typical and dug-up chernozems is plowed they are interpreted on black and white aerial

photographs according to the uniform dark grey tone of the photo image (fig. 1a). Due to the minor breakup in the relief of the examined territory these soils have soil contours considerable in dimensions and slightly irregular in form encompassing on the whole watershed spaces.

On the gently sloping inclines to ravines according to the striated illustration of the photo image one can with assurance interpret the contours of the typical chernozem with normal effervescence, the chernozem with reduced effervescence, the surchin dug-up chernozem and the chernozem of light and medium erosion on timber-like loam. In the narrow gently-sloping hollows on the slope, meadow-chernozem leached soils are formed. In the content of humus in the upper layer of the soil 7-8% they are close to the typical chernozems, but have a more extended humus bed, thickness 90-100 cm. The edge sections of the hollows are often somewhat more eroded than the surrounding territory, the carbonates from the surface have a grey or light grey photo image on the aerial photograph.

On the aerial photograph, by the dark grey tone and elongated soddy form one can with assurance identify large steppe ravines with meadow-chernozem leached, thick and super-thick alluvial soils formed on the ravine talus. They are covered with natural mixed-grass-grass vegetation and in an economic sense are pasture sections. Steep short slopes of the ravines are also covered with grassy vegetation. Typical chernozems are formed on them with reduced effervescence, surchin dug-up chernozems and eroded chernozems. In a number of cases, on the detailed aerial photographs according to the fine dotted nature of the illustration of the photo image differences are very noticeable in the degree of digging-up by the excavations of steep slopes of ravines depending on their exposition. The analyzed aerial photograph refers to the fall period. Therefore in its central section is clearly visible the striation of the photo image related to the autumn plowing of the field, covered with stubble and having on the aerial photograph a light grey tone of the photo image. In the lower edge section of the aerial photograph one can with assurance interpret the contour of the field on which harvesting of the corn into silage is underway. The central section of the field, according to the grey color and striated illustration of the image of individual rows of unharvested corn, is well differentiated from the light grey edge where the corn has already been harvested.

Comparison of the image of the soil cover on black and white aerial photographs of the same time of photography and the same scale obtained from panchrome and spectrozonal film revealed the following: on the black and white photographs

obtained with spectrozonal film, the fields which are occupied with sowings or stubble and plowed sections are more contrasting among themselves. On the plowed field the light and medium eroded chernozems and meadow-chernozem soils confined to the hollows and especially to the microsinks are more noticeable. On the whole the photo image of these two aerial photographs is similar. Detailed photography of the examined territory on the color film and its subsequent printing on black and white paper did not reveal any advantages in comparison with panchromatic film in relation to the photo image of the soil cover. However, in color printing it is easier to interpret the aerial photographs, since the image of the soil-vegetation cover on them has a natural color. Several aerial photographs show the possibilities of interpreting the soil cover of this territory with a break in a year, as applied to the spring, summer and fall period of photography. On the aerial photograph of the early spring period of photography of the watershed section, clear interpretation is made according to increased moisture content of a contour of a dark tone confined to the planar amphitheater around several hollows. This contour is traced well both by the surface of the plowed field and through the image of the previous year's stubble. Field studies of the soils on this section showed that in this contour typical, thick chernozems with reduced effervescence dominate, while meadow-chernozem soils dominate along the flat, hollows weakly expressed in the relief. In the spring period it is difficult to distinguish the typical chernozems with reduced effervescence and the meadow-chernozem soils on the aerial photographs. /150

In the summer and fall periods of photography the contour of the thick, typical chernozems with reduced effervescence is not distinguished from the typical chernozems. On the contrary, on the overall dark grey background of the image of typical chernozems the contours of the meadow-chernozem soils are distinguished well by the darker tone and soddy-like illustration of the image. There is yet another component of the soil cover of the watershed section which is interpreted well on the early spring photographs--these are the meadow-chernozem soils which are formed in the microsinks. On the aerial photograph they are depicted on the plowed field as spots of a round shape of grey tone (the image of weed vegetation) with a narrow ring of a dark tone around them (sections with increased moisture content in the soils). According to the aerial photograph of the early spring period (section of near-watershed slope) a clear interpretation is made of the light irregularity of the slope with shallow hollows with meadow-chernozem soils and contours of light and medium eroded, typical chernozems. This nature of the photo image of the soil cover is mainly analogous also for the aerial photographs of the fall period of photography.

On the summer aerial photographs these features of the photo image for the soil cover are not examined through a cover of agricultural crops. However, according to the nonuniform grey and dark grey tone of the image for the fields the variegation is clearly noticeable in the maturation of the sowings. On the aerial photograph of the early spring period narrow strips of freshly-harrowed sections of soils are very sharply distinguished according to the dark grey tone of the photo image (due to the difference in moisture content with the main background of the fields). On the plowed sections with uniform drying of the surface, the differences in the photo image of soils of a uniform mechanical composition are primarily related to the difference in content of humus and carbonates. If the typical thick chernozems have in the upper layer 6-7% humus and contain carbonates from a depth of 50-70 cm, then they are depicted by a dark grey tone. The weak-erosion differences of the typical chernozems contain humus in the tillable layer about 5%, carbonates 2-3% (according to CO<sub>2</sub>) and are depicted by a grey tone. The middle-erosion differences of the chernozems contain humus about 3% and less and 5-6% carbonates (according to CO<sub>2</sub>). They are depicted on the aerial photograph by a light grey tone. The meadow-chernozem leached soils, located in the hollows or sinks, are interpreted on the overall background of the image of typical chernozems according to the darker tone, due to their increased moisture content. The meadow-chernozem leached and meadow-chernozem alluvial soils formed in the bottoms of steppe ravines are very sharply interpreted according to the dark tone of the photo image on the spring aerial photographs.

On the aerial photographs of another period of photography (summer, fall) these /151 differences between the bottom (meadow-chernozem soils) and the slopes of ravines (chernozems) are not traced or interpreted with difficulty. In the mouths of the ravines on the spring photographs the snow is isolated by a strong light tone.

The results of the evaluation of the interpretation of the soil cover according to the black and white photographs obtained with panchromatic, spectrozonal film for different photography time (table No. 1) reveal that the greatest information content is found in black and white panchromatic and especially spectrozonal aerial photographs of the spring and fall periods. At the same time it was established that only in the early spring period, according to the excess moisture in the soils (the change in /152 tone) could contours be isolated with dominance of typical chernozems of reduced effervescence. The summer photographs have the greatest importance for calculation of the growth of various agricultural crops, the detection of centers of plant diseases and evaluation of their productivity.



TABLE 1

EVALUATION OF THE INTERPRETABILITY OF THE SOIL COVER ACCORDING TO BLACK AND WHITE AERIAL PHOTOGRAPHS OBTAINED WITH PANCHROMATIC AND SPECTROZONAL FILM FOR DIFFERENT TIMES OF PHOTOGRAPHY \*

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Name of soil contours	Large-scale aerial photographs		Aerial photographs of detailed scale			
	pan-chrome fall	SN-2M fall	pan-chrome spring	SN-2M spring	SN-2M summer	SN-2M fall
1	2	3	4	5	6	7
1. Chernozem typical, thick with normal effervescence, chernozem typical with reduced effervescence and chernozem dug-up surchin on timber-like loam	4	4	4	4	3	4
2. Chernozem typical thick with reduced effervescence and chernozem typical, thick with normal effervescence on timber-like loam	2-3	2-3	-	5	-	-
3. Chernozem typical, thick with normal effervescence, chernozem dug-up surchin, chernozem typical, light and medium eroded on timber-like loam	4	4-5	5	5	2	5
4. Chernozem typical, lightly eroded on timber-like loam	3-4	3-4	4	4	1	4
5. Chernozem typical, medium eroded on timber-like loam	4-5	5	5	-	3-4	5
6. Chernozem typical with normal effervescence, chernozem typical with reduced effervescence, chernozem dug-up, chernozem typical, eroded of steep ravine slopes	5	5	5	-	5	5
7. Meadow-chernozem leached on talus loam, confined to micro sinks	3	4	-	5	3-4	-
8. Meadow-chernozem leached on talus loam, confined to hollows	4	5	5	-	3-4	5
9. Meadow-chernozem leached and meadow-chernozem alluvial on ravine talus	4	4	5	-	3-4	4

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\*Visual evaluation of the interpretability in this and the following tables was made according to a five-point system: very good--5; good--4; satisfactor--3; poor--2; not interpreted--1.

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We will now examine materials of interpretations of multizonal photography of the soil cover of the same section of the Kursk site. For comparative study black and white photographs were selected which were obtained from isopanchrome type 17 film in five ranges of the spectrum with effective wavelength of 0.499, 0.519, 0.587, 0.637, 0.671 mcm. The analysis of the image of the soil cover and the agricultural lands according to aerial photographs was made both under laboratory and field conditions. The aerial photographs obtained in the zone 0.499, due to the poor quality of the photo image were unsuitable for the work. The evaluation of the interpretability of the soil cover according to the black and white multizonal aerial photographs of the spring period of photography 1973 (table 2) revealed that:

TABLE 2

EVALUATION OF THE INTERPRETABILITY OF THE SOIL COVER ACCORDING TO BLACK AND WHITE MULTIZONAL AERIAL PHOTOGRAPHS (PHOTOGRAPHY IN MAY 1973)

Name of soil contours	Large-scale aerial photographs				
	isopanchrome film, effective wavelength in mcm.				SN-6M
	0.519	0.587	0.637	0.671	
1	2	3	4	5	6
1. Chernozem typical, thick with normal effervescence, chernozem typical with reduced effervescence and chernozem dug-up surchin on timber-like loam	3-4	5	5	5	5
2. Chernozem typical, thick with reduced effervescence and chernozem typical, thick with normal effervescence on timber-like loam	1	1	1	1	1
3. Chernozem typical, thick with normal effervescence, chernozem dug-up surchin, chernozem typical lightly and medium eroded on timber-like loam	2	4	5	5	5
4. Chernozem typical lightly eroded on timber-like loam	2-3	4	5	5	4-5
5. Chernozem typical medium eroded on timber-like loam	3	4-5	5	5	5
6. Chernozem typical with normal effervescence, chernozem typical with reduced effervescence, chernozem dug-up, chernozem typical, eroded of steep ravine slopes	2-3	3	5	4	4
7. Meadow-chernozem leached and meadow-chernozem alluvial on ravine talus	3	4	5	5	3
8. Meadow-chernozem leached and meadow-chernozem alluvial on ravine talus	2	3	5	5	5

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The most complete and clear interpretation of the soil cover occurred according to photographs obtained in the zone of the spectrum with effective wavelength 0.637 mcm. The tone and illustration of the photo image were used for a sure differentiation of the soil contours of typical thick chernozems with normal effervescence, typical chernozems with reduced effervescence, dug-up surchin chernozems from the contours of typical, thick chernozems with normal effervescence, dug-up surchin chernozems, typical chernozems, lightly and medium eroded. Among the latter the lightly and medium eroded chernozems can be distinguished by the intensity of the tone. The near-ravine slopes with narrow hollows and meadow-chernozem leached soils confined to them are clearly interpreted. On the grey background of the image of the typical chernozems one can with assurance isolate the chernozems of steep near-ravine slopes according to the dark grey tone. According to the nature of the photo image of agricultural lands on these photographs (table No. 3) the fields are very well interpreted with winter crop sowings; sections under fallow, stubble and gardens. The freshly-harrowed fallow is well identified (according to the increased moisture of the soil surface); the sown to grass slopes with perennial grasses. Sprouts of barley, peas and vetch-oats are not interpreted. Their image has a similar tone to the fields under fallow. On these fields the surface of the soils is visible. As a result one can most effectively use aerial photographs of this time of flight for studying and interpreting the soil cover. /154

According to the nature of the photoimage of the soils and agricultural lands on the aerial photographs, the photographs obtained in the spectral zone with effective wavelength 0.671 mcm are the closest of all to the examined material.

The zone with effective wavelength 0.587 mcm proved important. Aerial photographs taken in this zone showed that on a field of winter rye dark bands are interpreted in addition which are related to the nature of the plowing of this field. Considerably less often there is noted a contrast between the black fallow, dried from the surface, and the freshly-harrowed fallow. According to the change in the grey tone it was possible to differentiate the field with young sprouts of peas from the field with sowings of vetch-oat mixture.

At the same time, the image of the soil cover of the sloping section with young sprouts of barley did not have a sharp nature. According to the tone of the image, the sections used for stubble or occupied with perennial grasses merged with the surrounding territory and were interpreted with difficulty.

TABLE 3

EVALUATION OF THE INTERPRETABILITY OF AGRICULTURAL LANDS ACCORDING TO BLACK AND WHITE MULTIZONAL AERIAL PHOTOGRAPHS (PHOTOGRAPHY MAY 6, 1973)

Name of lands and their state	Large-scale aerial photographs				
	isopanchrome film, effective wavelength in mcm				SN-6M
	0.519	0.587	0.637	0.671	
1	2	3	4	5	6
A. Fallow	2-3	4	5	5	5
B. Freshly-harrowed fallow	3-4	5	4	5	5
C. Winter rye	3-4	4-5	5	5	5
D. Vetch-oats (sprouts)	1	3	1	1	2-3
E. Peas (sprouts)	1	1	1	1	1
F. Barley (sprouts)	1	1	1	1	1
G. Perennial grasses (2nd year)	-2	2	4	3	3
H. Orchard	2-3	3-4	5	5	4
I. Stubble	1-2	2	5	4	2-3

Aerial photographs obtained in the spectral zone with effective wavelength 0.519 mcm had low-contrast photo image. Therefore additional information was not obtained.

Thus, the studies showed that for interpretation of soils and agricultural sowings it is most expedient to use aerial photographs obtained in two zones of the spectrum 0.637 and 0.587 mcm. The use of these photographs mutually supplement and enrich the information on the soil-agricultural resources of the earth.

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Ye. V. Glushko

At the present time numerous experiments have established the promising nature of determining the specific characteristics of the underlying surface according to the data of aerial photographic indications. It is natural that the use of different materials of aerospace photography produces a different probability of recognition, fluctuating about 80-90% (from 60-99%). In the development of methods of remote tracing of natural formations on test sections it is important to reveal the relationships between the specific characteristics of the underlying surface and the parameters of their remote image, the measures of their mutual correspondence and detailed nature of the interpretation, as well as the probability of recognizing the targets. It is necessary to establish the most favorable conditions of photography: climatic, weather and time. Further, identification of specific natural formations can be implemented by the developed technique in similar natural-climate conditions with limited field control or without it [5, 16]. This makes it possible to conduct an investigation of large territories according to previously established signs without additional collection of ground information.

Thus, maps were compiled for heat nonuniformities of the earth's surface by recording the radiation temperatures from an AES (artificial earth satellite) [7]. A considerable volume of remote studies were made on the state and productivity of vegetation by aero- and space measurements of the coefficients of spectral intensity [2,10]. Maps for the distribution of the snow cover both in plains and in mountain regions were compiled according to space TV images more exactly than by interpolation of the data from the dispersed network of meteorological stations [11]. As shown by the experimental processing of small-scale space TV and photo images, the ground system of collecting agrometeorological data and, in particular, information on the state of the soil surface provides in regional investigations less specific and accurate information than the maps and schemes of interpreting space images [4].

This work presents the experimental tracing of the change in moisture of the soil surface during the spring snow melting in accordance with the technique of interpreting remote recording of natural formations with limited or without ground information. The need for using for these purposes regional space TV images (for example, for arid regions of Kazakhstan) is explained by the requirement for the timely calculation of the provision with moisture and readiness of the soils of sowing areas

and feeding lands on the territory in area of tens and hundreds of thousands of square kilometers simultaneously. The network of agrometeorological stations which ensures collection of information about the condition of the soil, gives information for small sections only in regions where the stations are located. In addition, the network of agrometeorological stations does not provide information on the moisture of the soil surface during the spring snow melting and redistribution of snow melt water.

Theoretically the method of determining the moisture in the soil surface according to the materials of aerospace photography is based on the use of the complex relationship between the photometric indices of the image and the optic properties of the surface layer of soils of varying moisture content. Many of their characteristics and correlations were obtained previously on key sections in Central Asia and South Kazakhstan [1, 3, 9], in North Kazakhstan [3, 12, 13] and in the plain regions of the USA [19]. This served as the basis for conducting large-scale studies of the soil moisture content in the visible zone of the spectrum in arid and semiarid zones according to aerial photographs [1, 12, 13, 22, 23]. Differences in the moisture of the underlying surface were also recorded by space TV images [3, 17, 21], by multispectral images [20] and photographs [18] with a limited number of ground data or without them. /157

The experimental remote determination of the moisture content in the soil surface was completed by us according to the regional TV images obtained from the AES "Meteor-1" in a pattern of direct transmission on April 4, 1973 at 13 hours Moscow time (15-15 hours MV). They encompass about 230 thous. sq. km in three natural zones of North and Central Kazakhstan from the moderately arid steppe to the northern desert (fig. 1). TV photography occurred from an altitude of 900 km with slope angle  $\sim 20^\circ$  from the vertical on a scale from 1:8,500,000 in the subsatellite point to 1:11,250,000 in the edge section of the original image with resolution on the site of area targets of moderate contrast 2-5 km, of linear targets of high contrast  $\sim 1$  km.

The lack of a cloud cover over the region of study during the photography, the identity of the subsequently obtained images according to technical characteristics, scale, visibility, time of photography and meteorological conditions ensured a fairly high information content and good comparability of the TV photographs. However, the instability of the TV photography signal elicited noticeable distortions in the density of the negative image which impaired identification of the levels of moistening of the surface.



Laboratory interpretation of the TV images was preceded by ground surveying route work in July 1973 in the Kustanay and Turgay regions. They included comprehensive geomorphological and soil-geobotanical characteristics of landscapes necessary for interpreting the television images.

As indicated by the data from the network of meteorological stations, the winter snow cover on the greater part of the territory came off still up to April 1 and was preserved only on 12% of the area. However, on April first on the trans-Ural plateau and the Kustanay steppe there was an abundant snowfall which covered the surface with a layer 10-15 cm thick which increased the snow-covered area to 26%. In the period of photography over the region of study there was cloudless weather without precipitation. The positive daily average air temperature  $+1$ - $+5^{\circ}\text{C}$  and of the underlying surface  $+1$ - $+3^{\circ}\text{C}$  produced intensive snow melting. By April 4 the snow cover was maintained only in the most northern regions.

For the given region April is a month with the least stable amount of fallen precipitation, even the average five-year fluctuations in the amount of precipitation reach six times. The spring of 1973 was especially dry and as a result on the TV image rapid drying of the soils is traced which determines the spring drought. The development of this drought was also reflected on the TV image of the watershed spaces.

The moistening of the surface horizon of soil was evaluated visually according to the positive TV images sensitized in the red zone of the spectrum ( $\lambda\lambda=0.5-0.75$   $\mu\text{m}$ ), that is in the range where the correlation between the moisture content of the surface soil layer and the tone of the image is most stable [15]. Moreover, in this zone of the spectrum the effect of fluctuations in soil temperature is excluded. Identification of the moisture content in the soils by space TV images is limited by the characteristic of moisture in the surface "film" of soil comparable with the wavelength  $\leq 1\mu\text{m}$ , corresponding to the thickness of the active layer of light reflection. However, the moisture content of this "film" correlates with the moisture content of the upper soil horizon. By using the established relationship between the reflection of light from the soils of varying moisture and the density of the negative image [3] the following task was successfully solved: according to the tone of the positive image to differentiate the five main agrometeorological gradations in moisture of the soil corresponding to the primary stages of surface drying. However, the results of identification of the soil moisture did not successfully express in quantitative amounts the moisture content since during the TV photography the agrometeorological stations on the given territory had not yet

measured the soil moisture.

Evaluation of the tone of the positive image was made by sight according to the 158 degree of density of the print using a seven-point scale of black-white tones according to the dominant tone or a combination of tones within the section. The determining factor in the change in moisture and optical characteristics of the comparatively low-humus chestnut soils is the texture. With a humus content of the chestnut soils less than 2.5%, its effect on the order is above the effect of other factors. As is known, with an increase in the moisture of the soil its intensity decreases, which results in a rise in the tone of the positive image. However, the high-gradient section of the link between moisture and intensity of the soil is limited for soils of varying texture by the specific interval of moisture established experimentally by measuring the reflecting properties of different samples of the surface horizon of achromatic soils. [3, 9, 12]. For sands the interval from 1% to 6-8% is characteristic, for sandy loam from 1-2% to 8-10%, for light loam from 2-3% to 22-26%. The reflecting properties of the soils outside the indicated intervals of moisture vary insignificantly. With moisture content below this interval the soils are primarily light, above it--dark.

The TV images were interpreted according to a photomontage composed of fragments of four prints enlarged to a scale of 1:2,850,000 with the use of small-scale mapping and descriptive materials. Consideration was also made for reports of meteorological and agrometeorological stations for the first ten days of April 1973 (including data on the cloud cover, precipitation, distribution and thickness of snow cover, dates of departure of snow, temperature of air and soil).

The interpretation of the soil moisture also took into account the effect on the photometric characteristics of the TV image of other soil factors (humus content, mineral and mechanical composition, easily-soluble salts, structure of surface horizon of soil) and the remaining landscape components: vegetation, relief and quaternary deposits.

The distribution of surfaces with varying moisture content of the soil depends mainly on the following natural and meteorological factors: on the periods of freeing the surface from the snow cover, on the orientation of the slopes of the relief and the arrangement of the centers of water-collecting basins, on the breakup of the relief and the height difference of the site above rivers and lake surfaces.

The region of study was characterized at this time by favorable natural conditions

for interpreting the moisture content of the soil. The lack of sprouts of virgin soil and crop vegetation and the lack of plowing during the photography determined the direct dependence of the optical characteristics on the soil moisture. The plain relief, as a consequence of insignificant slopes, creates identical conditions of surface illumination and does not have a varying effect on the tone of the image. The soil cover on the TV image is not differentiated by zonal types since for this differences are necessary in the humus content of over 1% [13] under close conditions of moistening of the surface. However, the southern chernozems (humus content 5-6%) and the dark chestnut soils (humus content 3.5-1.5%), which significantly surpass in humus content the dry southern low-humus soils (chestnut 2-2.5%) during the photography were universally damp and wet which determined their homogeneous dark tone of the image. Therefore, the differences in humus content of these soils are exceeded by the more considerable optical contrasts related to the differences in moisture. The effect of the humus content on the image tone of moderate and insufficiently moistened, low-humus soils is universally the same. The dominating zonal types of soils with a low content of humus (chestnut 2-2.5%, light chestnut 1.5-2%, brown 1-1.2%) in the dry state have on the TV image a lightish grey and light grey tone and are not differentiated among themselves due to the insufficient differences in humus content.

In addition, the tone of the soil image changes depending on the moisture content of the soil associated with their texture which under plain conditions determines the water-retaining capacity of the soils, and consequently their moisture content, and correlates well with the optical characteristics of the TV image. The soils of light texture and the same moisture content are darker than the heavy ones. The structure of the soil surface also affects the tone of the image since the unplowed soils with smooth surfaces (lighter) with an increase in moisture have more contrasts of density of tone and have a darker tone than the plowed soils with irregular surface. Local changes in the soil conditions in the limans and hollows with rich-in-humus soils, on the outcrop of rocks with dark or on the contrary lightly colored soils, as well as on saline soils were excluded. /159

Differentiation of the snow cover (coefficient of spectral intensity  $\sim 0.7$ ) and the soils with air-dried surfaces (coefficient of spectral intensity  $\sim 0.3$ ) having on the TV image difficult to delimit by sight light- and lightish-grey tones, can be conducted according to the density of the negative with the help of densitometric measurements. In addition, relatively warm, dry soils are well differentiated from cold, snow-covered plains according to the IR images in the interval  $\lambda\lambda=8-12$  mcm,

especially daytime [8].

The TV image was used to separate five main agrometeorological gradations in soil moisture according to the dominant tone of the image and they were compared with the physical gradations given in percentages.<sup>1</sup> The difference in the amount of moisture of adjacent gradations on the average was 4-5%. 1. wet (flowing state with moisture of loam soils > 26%)--dark tone, 2. moist (sticky state with moisture 18-26%)--dark and darkish-grey tone, 3. damp (light-plastic state with moisture 9-18%)--grey tone, 4. fresh (hard-plastic state with moisture 3-9%)--lightish-grey tone, 5. air-dried (hard and loose state with moisture less than 3%)--light grey tone (fig. 2). In separating these gradations of moisture according to the TV image (which usually are recorded in agrometeorological observations at the stations) previously established evaluation criteria for visual quantitative determination of agrometeorological levels of soil moisture were considered [6, 15]. The surfaces with these gradations in moisture are well distinguished according to the photographs on the leveled inter-river spaces. In addition, on the slopes of the Turgay and trans-Ural plateaus and in the river valleys on the TV image combinations of moisture gradations were isolated. Determination of the structure of the TV image of surfaces with different moisture content showed that the surfaces both with excess and with insufficient moisture present a homogeneous tone of the image, while moderately moist (damp and fresh)--heterogeneous. The homogeneity of the tone in the image of wet, moist and air-dried surfaces is related to the fact that the moisture gradients are insignificant and do not present sufficient optical differences within the mentioned moisture intervals. The heterogeneity of the image tone of damp and fresh surfaces is a result of the fact that in these intervals the moisture gradients governed by the structure of the mesorelief present the greatest optical nonuniformities. The presence of a well expressed heterogeneous structure of the image indicates the readiness of the soils for plowing.

Below are presented the characteristics of the positive image of all the gradations of soil moisture in the order of tone lightening. The correlation of the areas of separated soil areas according to the gradations in moisture was computed in percentages of the area of the image of a surface without snow cover.

1. Surface layer of soil wet--on strongly over-moist in places swamped, plakor depression and wavy-plain surfaces in the centers of water-collecting basins. On the

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<sup>1</sup>The correlation of agrometeorological estimates of the moisture and readiness of the soil and the physical amounts was conditionally accepted [6].

TV images it is characterized by the dominance of homogeneous dark tone, disrupted by rare light-grey, sharply outlined round spots, corresponding [to] lakes with ice, individual grey spots of dried elevations. On the TV image it occupies 23% of the area.

2. Surface layer of soil moist--on wavy-plain surfaces of flat interfluvial areas. On the TV image it is represented by a dominant rather uniform dark-grey tone, turning into darkish-grey on the image of more dried surfaces. It occupies 11% of the area.

3. Surface layer of soil damp--on beyond lake wavy-plain and wavy-plain ancient-bench surfaces, as well as river-floodplain and floodplain-liman surfaces. On the TV image it is characterized by the dominance of a uniform grey tone, in individual regions it becomes a darkish-grey tone, corresponding to moister depressions, and a lightish-grey tone in the elevation of the relief. The structure of the image of the river valleys is complicated by the presence of narrow, winding strips of a lightish-grey tone corresponding to the riverbeds. It occupies 25% of the area.

4. Surface layer of soil fresh--on slopes, wavy-plain and elevated-plakor surfaces. On the TV image it is characterized by nonuniform lightish-grey tone. It occupies 6% of the area.

5. Surface layer of soil air-dried--on elevated-plakor surfaces. On the TV image it is characterized by homogeneous light-grey tone, from time to time disrupted by lightish-grey spots with indistinct borders corresponding to depressions with fresh soils. It occupies 12% of the area.

More complex structural pictures and combinations of the aforementioned elementary fields occur on slopes, elevations and other sites with broken up relief.

6. Surface layer of soil represented by alternation of wet and moist surfaces--on near-river spaces abounding with swamped depressions and lakes in regions of concentration of snow melt water. On the TV image it is characterized by the alternation of slightly dominating rather uniform dark-grey surfaces corresponding to the moist soils with large spots of a homogeneous tone of linear-elongated or irregular form with indistinct borders, corresponding to the more over-moist depressions. The structure of the image is complicated by the presence of narrow, winding strips of a lightish-grey tone, corresponding to the river beds and round light-grey spots with sharp borders, corresponding to the lakes covered with ice and reservoirs. On the TV image

they occupy 7% of the area.

7. Surface layer of soil represented by a combination of wet, moist, and damp surfaces--on talus-slope plains. On the TV image it is characterized by alternation of small dark- and darkish-grey spots and strips corresponding to wet and moist depressions, and grey surfaces corresponding to elevations with damp soils. The structure of the image is small-spotty. It occupies 8% of the area.

8. Surface layer of soil represented by alternation of moist and damp soils--on well drained, near river spaces. On the TV image they are distinguished by a combination of surfaces of nonuniform darkish-grey tone, corresponding to the moist depressions, gradually changing into a grey tone on the elevated damp surfaces. The structure of the image is complicated by the presence of narrow, winding strips of a grey tone with indistinct borders, corresponding to river beds. It occupies 8% of the area.

### Conclusion

Determination of the nature of the moisture content of the surface during the spring snow melting in the North and Central Kazakhstan on an area of about 230 thous. sq. km. showed the following distribution of the surfaces according to degree of moistening: excessively moistened wet surfaces occupied 48% of the area, moderately moistened damp and fresh (ready for plowing soils)--40%, insufficiently moistened air-dried--12%. The presence of moderately and insufficiently moistened surfaces by April 4 on the greater half of the studied territory indicates the early drying of the surface which was one of the reasons for the formation of drought in 1973. /161

There remains the problem of correlating the optical properties of the soil surface of different moisture with the profile of soil moisture. However, the relationship between the density of the TV image and the agrometeorological gradations of moisture in the upper horizon of soil in the pre-planting period between the freeing of the soil from snow and until complete readiness of the soil for plowing, as indicated by the analysis of the aforementioned material, does exist. Further, the standardization of the values of image density, and in particular, the development of multizonal photography of the soil moisture, permits the technique of space photography of the soil moisture to become more universal. The combination of channels at least  $\lambda\lambda=0.6-0.7$  mcm and  $\lambda\lambda=8-12$  mcm is necessary. The frequency of the photography during the greatest time gradients of moisture can reach once in 1-2 days,



although at another time could also be less. After, the obtained local time of photography, about 16 hours, was favorable for recording soil moisture.

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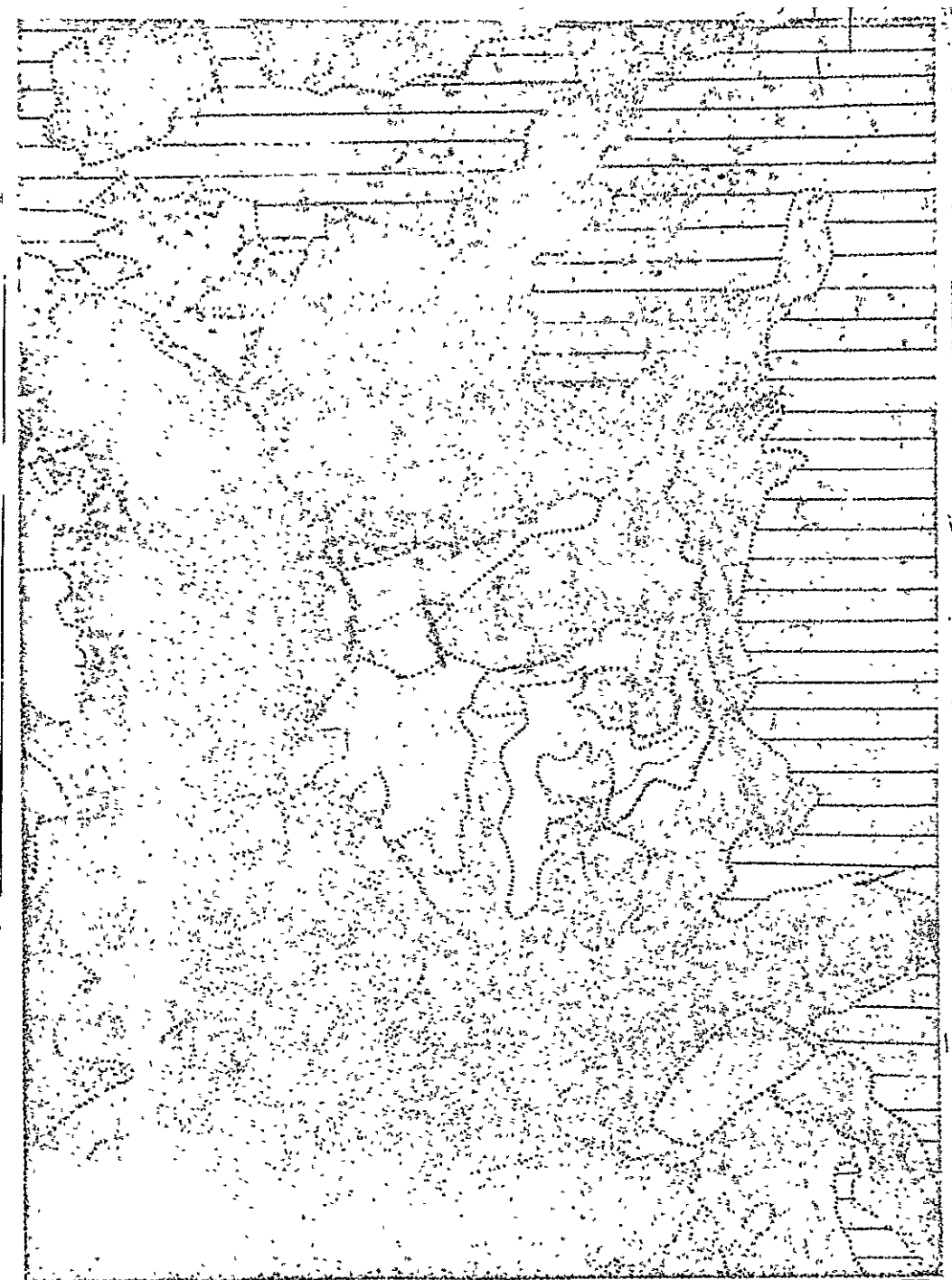
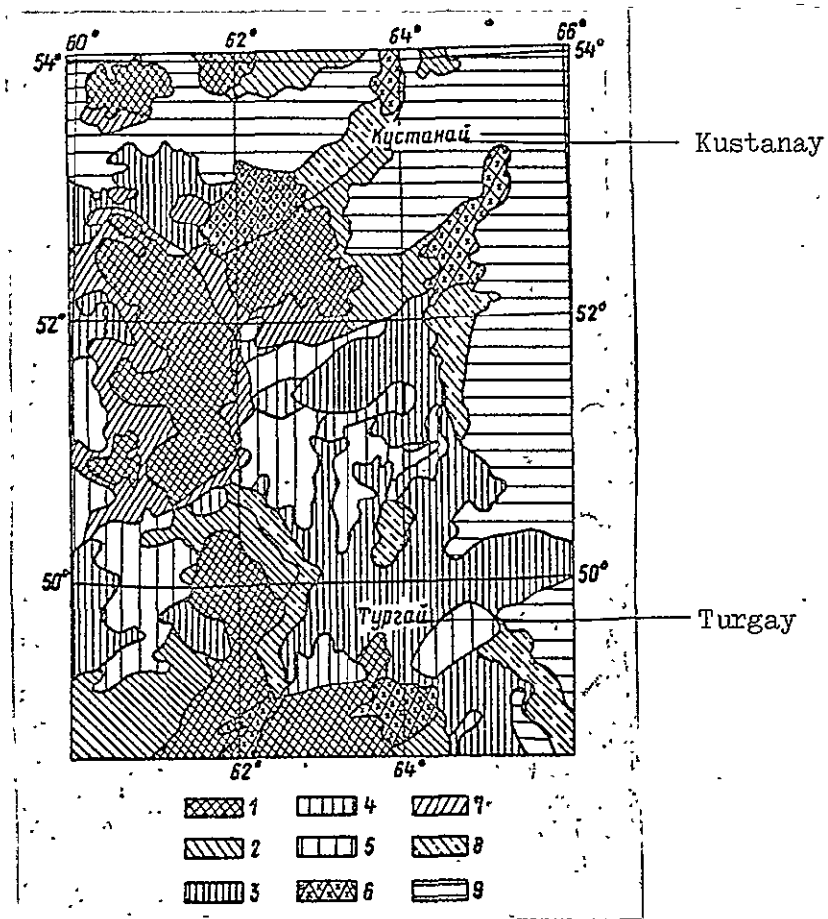


Fig. 1. Montage of TV images obtained from AES 13th "Meteor-1" on April 4, 1973, 13 hours Moscow Time.

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Fig. 2. Schematic diagram of interpretation of moisture in surface layer of soil according to TV image from AES 13th "Meteor-1" April 4, 1973. Gradations in moisture of surface layer: 1--wet, 2--moist, 3--damp, 4--fresh, 5--air-dry; combinations of elementary fields of moisture: 6--wet and moist; 7--wet, moist and damp, 8--moist and damp, 9--snow.



S. M. Aleksandrov

The small-scale TV image that we analyzed was obtained in two zones of the electromagnetic spectrum (0.6-0.7 mcm, 0.8-1.0 mcm) on August 21, 1974 at 9 hours 32 min. Moscow time on the territory of Kazakhstan, Central Asia, Afghanistan, Iran and Pakistan. TV images of larger scales were used for comparison.

In our interpretation we used the principle developed by I. P. Gerasimov (1959)-- analysis of the expressiveness of different-age tectonic structures in the relief and the correlation of the morphosculptures and morphostructures.

According to the scale from 1:10,000,000 in the center of the image to 1:20,000,000 along the edges and coverage of an area over 3 mill. km<sup>2</sup>, the photograph approaches the global images of the "Zond" system.

The obtained information (fig. 1, 2) was compared with the topical load map FGAM and the large-scale schematic diagrams (Kulakov, 1968, Arkhipov, Nikonov, 1974, et al.). The traditional correlation of the scales of remote photography and updated maps was 1:2-1:5, therefore one could consider the information sufficient that permitted supplementing of the maps and schematic diagrams of a scale 1:20,000,000-1:50,000,000.

In the morphotectonic aspect, the photograph encompasses an extremely complexly structured territory whose main elements are the regenerated epiplatform mountains of Upper Asia (Tyan'-Shan', Himalāyas), the plains of epihercynian platform (Turan lowland) and epigeocynclinal mountains of the eastern part of the Alpine belt (Pamir, Suleymanovy). It is important that on the global photograph "Zond-7" with a distance about 70 thous. km. precisely these larger (geotextural) elements are clearly distinguished.

In the morphological (neotectonic) aspect contrasts are observed here which are close to the maximum on the earth, from 7000-8800m in Pamir and Himalayas, to -100 m on the Turan lowland.

Finally, in the morphoclimatic aspect, due to the vertical differentiation on the overall arid background, great contrasts in flooding and energy of relief-forming processes are laid on.

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The general features of the morphostructure, the newest tectonics and of the morphosculpture are presented in table form.

We will examine the interpretation signs of the studied morphostructures and morphosculptures. Analysis of the TV image was made by the author on the basis of field observations in 1964 ('East Tyan'-Shan'), in 1972 (Balkhash region), in 1973-1975 (Fergana hollow and its mountain framework, Pamir), and studies of the background and published materials.

One of the main interpretation signs is the illustration of the image. For the characteristics of another interpretation sign--optical density of the image on the print--a system was used of visual point evaluations of the gradations in grey tone scale whose principle of use was examined by L. N. Mukhina (1974). We compiled a transitional table of visual seven-point scale of tones and calibrated field of TV image containing 19 gradations in optical density (table 2).

1. Platform plains of region of Baykal folding (see table 1 and fig. 1). Their /167 image is on the section of the greatest geometrical distortions, therefore the contours in comparison with the actual are very deformed. Despite the differences in hypsometric elevations of the plains there is a similarity in the illustration and tone reflecting the common character of the type of morphostructure and morphosculpture.

For the Tar desert (1.B) a structureless illustration with tone IV-V is characteristic, differing sharply from the darker deflection of Ind (tone II-III) which should be explained by the thinness of the vegetation and the lesser degree of flooding. In the Takla-Makan desert (1A) which has the same tone (II-III), on the /168 background of sands (tone IV-V) a striated illustration is sharply distinguished of flooded oases of Aksu, Kashgar, Yashkend and Khotan (1) with tone II-III. The contrast of tones is greater in the zone 0.6-0.7 mcm, therefore it is more informative for interpreting the borders of the valley-oases. The illustration of the valleys on the space image is considerably more detailed than the hypsometric map of scale 1:10 mill. and the map of morphosculpture FGAM of scale 1:15 mill.

The illustration and tone of the deserts of ancient platforms differ little from the image of the deserts of the epihercynian platform which is characterized by the noticeable angularity of the platform outlines [2] which so graphically is not reflected even on the larger-scale maps.

TABLE 1

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TYPES OF MORPHOSTRUCTURES DISTINGUISHED ON THE SPACE PHOTOGRAPH, THE CHARACTERISTICS OF THEIR NEWEST MOVEMENTS AND PECULIARITIES OF MORPHOSCULPTURES

Index	Type of morphostructure	Type of neotectonics	Type of morphosculpture
1	2	3	4
I	Platform plains with Paleozoic-mesozoic sedimentary cover	Weakly differentiated movements	Accumulative with sections of denudation, arid
IA	Hollow of Tarim middle massif (abs. altitude 1300-1700 m)	Relative deflection of platform type (passive damper)	Aeolian with fluvial in transit valleys (Takla-Makan desert)
IB	Plains of northwest Indian platform (abs. alt. 100-200 m)	Relative deflection of platform type (active platform)	Aeolian (Tar desert)
II	Denudation plains of region of Paleozoic folding (Kazakh area of low, rounded isolated hills--abs. alt. 500-1500 m)	Low elevations of free type with intrusive diapirs, neotectonic troughs	Fluvial-talus on watersheds and slopes, desert solifluction in valleys
III	Activated epiplatform average high-altitude, high and highest mountains with intermontane hollows in region of paleozoic folding	Intensive differentiated elevations of linear type with depressions in intermontane hollows, limited by plutonic faults	Glacial-nival above snowline, erosion-denudation in average high-altitude mountains accumulative, semiarid in depressions
IV	Ancient average high-altitude and low mountains in region of Paleozoic folding (Chulili, Karatau and others abs. alt. to 3000 m)	Low and moderate elevations of linear type limited by plutonic faults of northwest course	Denudation semiarid
V	Platform plains of epihercynian platform with Mesozoic-Cenozoic sedimentary cover (Turan lowland abs. alt. to 1000 m)	Differentiated dips of isometric contours with local elevations	Denudation-accumulative arid (dominating ash)
VI	Young epigeosynclinal mountains of Alpine folding (abs. alt. to 7500 m)	Intensive differentiating orogenic elevations of linear type (arches, chains, clusters)	
VIA	Young mountains of early consolidation with outcrop of early-Alpine base (Gindukush, Pamir, Karakorum)	Intensive elevations with late paleogene, horizontal shifts	Glacial-nival in high mountains, arid denudation in average high-altitude mountains

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(continuation of table 1)

1	2	3	4
VI	Young mountains of late consolidation with outcrops of late Alpine base (north and south framing of Alpine belt) - Suleymanovy mountains Konet-Dach	Elevations of medium intensity, from late Miocene, in south considerable horizontal shifts	Erosion-denudation, semiarid
VI G	Middle massif of Alpine folding-Baykal base with Paleozoic-mesozoic cover (Central Afghan massif-Gil'mend hollow)	Elevations of low intensity with sections of deflection	Arid, fluvial in valleys
VID	Edge deflections of Alpine folding (Kopetdag, Tadzhik, Ind)	Differentiated depressions	Arid, fluvial in valleys

TABLE 2

COMPARISON OF GRADATIONS OF CALIBRATED FIELD WITH POINTS OF TONE SCALE

Gradations in calibrated field (on print)	Points	Visual characteristic of tone (on print)
1-6	I	Dark
7-8	II	Dark grey
9-10	III	Darkish grey
11	IV	Grey
12	V	Lightish grey
13-14	VI	Light grey
15-19	VII	Light

II. Denudation plains of region of Paleozoic folding.

In the analysis of the interpretability of this type of morphostructure we compared the information content of the TV image of a scale 1:12 mill. with photographs on a scale 1:3 mill. from the system "Salyut" and concluded that the main interpretation signs of the morphostructures are stable regardless of the scale.

These signs include tree-like-wavy illustration with tone III-IV, governed by a combination of low-rounded isolated hills composed of dark volcanic rocks (3) and narrow valleys whose bottoms are covered with loam-gypsum weathering crusts (4). The lineaments are traced more weakly than on the photograph from "Salyut" (Aleksandrov, Vinogradov, 1974) due to the lower resolution, but the overall orthogonal illustration of the disorders is preserved. A relatively dark tone II-III distinguishes the larger ring volcanic morphostructures--Karkaralin (5) and Kysylraysk (6); lightening (tone V-VI)--large granite massifs of Katbar and Bektauta (7). The morphosculptures--delta Tokrau (8); besides the light tone have a delta-like illustration.





The interpretation signs are stable regardless of the scales since this illustration is not repeated on the entire area of the image but is characteristic only for the area of low, rounded isolated hills, whereby the very specific, stressed by I. P. Gerasimov (1959) lack of linear morphostructures, with the exception of the newest lineaments. Low elevations and lengthy denudation, governing the preparation of stable rocks, are characteristic for the illustration and the combination of tones.

The information content of the image from the 18th "Meteor" is comparable with the hypsometric and geomorphological maps FGAM (World Atlas of Physical Geography) of the scale 1:10-1:15 mill. In light of the great contrast due to the sensitivity to differences in moisture content there are more details in the zone 0.8-1.0 mcm.

### III. Activated epiplatform mountains and intermontane hollows in the region of Paleozoic folding.

Due to the great intensity of the newest elevations, governing the considerable volume of glaciation, a great amplitude of tones (III-VII) is characteristic for the TV image. The problem of separating the snow and ice from the cloud cover according to the tone on the print is not solved in the examined zones of the spectrum, therefore there is a real need for using a radio-range of the maximum high resolution. It should only be noted that the glacial-nival cover in contrast to the cloud cover has a tree-like illustration (Khan-Tengri).

On the photograph in both zones two types of image are clearly distinguished: relatively dark, linear contours (tone III-IV) with narrow light strips of ice-nival cover (tone VI-VII) characteristic for the average high-altitude and high mountains of the periphery of Upper Asia; dominance (over 50%) of light tree-like illustration (tone V-VII) characteristic for high and highest mountains.

The most characteristic feature of the illustration of the image due to the dominance of block movements according to faults is, first, the rectilinearity of the outlines of the elevations and hollows sharply differing from the vergent outlines of the ridges in the zone of the Alpine folding. This is very significant, for example, for the mountain framework of Fergana.

The combination of the grey tone of the superimposed depressions (tone IV) and the dark tone (II) of the image of ridges is another important interpretation sign of this region. /169

Finally, the third characteristic sign is the round-radial illustration of the

highest mountain blocks and zones of the accumulation-massif of the peak Pobedy and Khan-Tengri, East Pamir, north Karakorum and Kuen'-Lunya. The light illustration of the glacial-nival zone according to area here exceeds 75%.

The plateau of southwest Pamir (9)--Shugnansk, Vakhansk, South-Alichursk ridges-- has a very unusual linear-round illustration and relatively uniform tone (V). On a number of tectonic maps this region belongs to the zone of Alpine folding, however the monotony of the TV image (leveling of the relief), vergent folds in the ridges of West Pamir and Gindukush on the border with the plateau confirm its rigidity and damper position of the middle massif or the ancient nucleus. Acquaintance with the regional materials convinces us of this hypothesis. S. S. Karapetov and E. Yu. Leven (1973) make the tectonic parallelization of South Pamir and South Afghan massifs, according to the data of E. S. Cherner and V. I. Budanov (1974) the composition of the deposits on the ancient crystalline foundation of South Pamir is close to the platform type, whereupon the ancient weathering crusts are fixed. Yu. S. Perfil'yev and V. M. Moralev (1971) to the north of Vakhans-Dar'ya distinguish the Badakhshan massif of ancient crystalline rocks limited on the north by Gunto-Alichursk, and on the south by South Pamir plutonic faults. The leveling surfaces developed in Afghan Badakhshan on the ridges Safed-khirs and Kukh-Lal (10) at altitudes 2800-3600 m go deep into Pamir in a tongue-shape and are preserved at latitudes to 4200 m (Nikonov, 1973, 1974; Donovan et al., 1974). It is possible that the general lightening of the tone in comparison with the substrate of the majority of ridges is related to the presence of loess-like loams at relatively great altitudes governed by the ancient alluvial activity of tributaries of the Pyandzh, the continuation of whose valley to the south is outlined towards the southeast of its sharp bend.

We will further describe the interpretation signs according to the large morpho-structural units from the hollows to the ridges adjacent to them.

The hollows are diverse in the genesis of the deposits filling them, dimensions, configuration and have in relation to this differences in the TV image. Common is the relatively same tone (IV) governed by the leveling of the relief and the domination of light arkose sandy and pebbly, loess or loam-saline soil deposits. The morphosculpture determines the tone, while the morphostructure the illustration of the image--rectilinear, angular outlines of frequently triangular form.

The Alakol'sko-Ebinur hollow (IIIH) is separated, for example, from the system of

Dzhungar Alatau (III A) by the rectilinear Dzhungar fault (11) which has the appearance of a straight line on the edge of a dark contour of the ridge (dark-colored effusives dominate) and light contour of the hollow (proluvial pebbles and talus loams). The fault is traced exceptionally clearly on all types of remote photography from 1:10 mill. to 1:10 thous. with varying degree of detail, whereupon on the large-scale photographs numerous fledgling and advanced shifts in the beds are seen (Voytovich, 1967). In this sense it can be compared with the unique faults of Talassofergana or San Andreas which are also characterized by advanced shifts. The reason for the good expressiveness of the faults is in their constant renewal and rectilinearity on a considerable distance, which also governs the sharp contrast in tone. Especially sharp is the contrast with the saline soils (tone VII) of the hollows of Ebinur (12). Less noticeable is the saline soil margin of Lake Alakol' (13) and even weaker of the mountain lake of Sayram-Nur (14) located in the center of the Borokhoro ridge. On the whole the great part of the Alakol'sko-Ebinur hollow, piedmont Tarbagataya, Zaysan hollow (III M) is composed of loess-like loams with tone III-IV, structureless illustration, on whose background are clearly traced only water basins, especially in the zone 0.8-1.0 mcm. The structure of the image in the bottom of similar hollows is traced only beginning with the scales 1:3 mill. in which flooded valley bottoms, dry watersheds, etc. are well distinguished. Generally the zone 0.8-1.0 mcm is more promising for analysis of the structure of valley bottoms than the interval 0.6-0.7 mcm. For example, on the image in the zone 0.6-0.7 mcm there is absolutely no separation of the water area of Lake Sasykol' (15) and the sandy connecting strips between the lakes, there is worse tracing of the contour of the Bukhtarmin reservoir (16) although the Dzhungar fault is traced better in the red zone (0.6-0.7 mcm). /170

The asymmetry of the mountain structure Dzhungar Alatau-Borokhoro is very well seen in the zone 0.6-0.7 mcm. and is stressed by the extensive development of the leveling surfaces with tone III on the north slope. There is clear separation of the latitudinal faults delimiting the Andreyev paleogenic hollow (17) total width of 5 km which is traced on the background of sedimentary-volcanogenic complexes due to the light timber-like rocks. In the zone of 0.8-1.0 mcm. these elements are isolated with great difficulty. Slight glaciation of the ridges is also recognized better in the red zone.

The Ili hollow (III O) in its geomorphological position, partly in the outlines and interpretation signs is close to the Zaysan and Alakol' hollows. The plains with loess-like loams have a structureless illustration with tone III-IV. In the zone 0.6-0.7 mcm individual insular mountain massifs are differentiated better--Ketmen' ridge (18), end of trans-Ili Alatau, and in the zone 0.8-1.0 mcm water basins.



are more clearly distinguished, for example, the Kapchagay reservoir created in 1971.

In the analysis of the interpretability of the TV image of the Balkhash hollow (III) great attention was focused on a comparison of the interpretation signs with the photographs of the Balkhash region on the scale 1:3 mill. The TV illustration of the sandy plains (19) is distinguished by monotony, which in general is characteristic also for the sandy plains on the photograph. The zone of flooding at the foot of the ridge Malay-Sary (20) is traced also on the photograph from "Salyut" and on the TV image from the "Meteor" in the zone 0.8-1.0 mcm, but, of course, with a different degree of detail. From other large morphosculptures, both on the photograph and on the TV photograph, but only in the zone 0.6-0.7 mcm, the ancient Bakanas reservoir delta of the Ili River (21) is recognized by lightening of the tone (IV) on the saline soil-takyr bottoms of the ancient beds and the clear striated illustration. The current Ili delta (22), more flooded and covered with thick tugai vegetation, has a grey tone (III-IV) and triangular illustration. This section of the delta can be classified with the natural phenomena in so far as its TV image is comparable in tone with the image of oases continuously occupied with crop vegetation (Bukharā, Samarkand, etc.). It goes without saying that the photograph gives more details in the structure of the Ili delta, individual beds are traced on it, bands of coastal cane thickets are mapped in detail, microdelta ledges jutting into the lake are recognized (the latter, by the way, are also visible on the TV image).

The matter is more complex for faults in the foundation under sandy plains where the depth of its occurrence reaches several dozens of meters. In the interpretation of the photograph we successfully established that the morphostructural lineaments C3 and CB of the course are traced according to different indirect signs: rectilinear limitations of saline soil hollows, rectilinear sections of the Karatal valley, series of extended lakes, etc. On the analyzed TV image only in the zone 0.8-1.0 mcm are linearly extended lakes and rectilinear sections of the shore visible. On the other hand, the Central-Balkhash fault on the TV image is traced well, due to the generalization of the image of the linearized Ili bed.

The images of the sandy desert plains of South Balkhash region and the Turan lowland are very similar both in the illustration and the tone. Attention is only drawn to the lightening of the tone of the Balkhash region desert roughly by 1 point, which obviously is governed by a defect in the photograph since north of Balkhash there is also a lightening of the tone.

The ridges of North and Central Tyan'-Shan' (trans Ili--III B, Kungey-- III B,



Kirgiz--III II', Terskey-- III E, Kokshaal-- III 3 ), hollows of the Naryn basin (Naryn-- III P, Toktogul'-- III T, Kysart-- III Y), Issykkul'-- III G. In this region we were limited /171 by observations along the intersection of Frunze-Osh and in the region of Alma-Ata. As the basic work on the morphostructure of Tyan'Shan' we used the monographs of I. P. Gerasimov (1959) and S. S. Shul'ts (1948).

Certain basic conclusions of the authors can be illustrated by the nature of the image of the relief on the TV image. For example, the idea on the combination in the formation of the morphostructure of Tyan'-Shan' of block movements as well as of deformations of the type large folds (Gerasimov, 1959, p. 29) find additional confirmation. Ridges bordering Fergana are linked at different angles, while the entire northeast face of West Tyan'-Shan' cuts off the Talasso-Fergana fault, which is active from the Cambrian period to the present. A completely different arched illustration, as if a projection of large folds, is characteristic for ridges bordering Issyk-Kul' and Naryn hollows. All the main signs of the zone for activated mountains: general linearity of ridges, presence of hollows and large mountain units, extensive development of glacial-nival belt in the first place refer to the region of Central Tyan'-Shan'. A common distinction in the image of Central Tyan'-Shan' from the West is the lesser differentiation of the relief: darker (tone III-IV), mountainous hollows contrast less with the high plateau ridges (tone II-III) than in the west.

The Fergana hollow (III D) with its mountain bordering (ridges Talas-- III II, Fergana-- III E, Chatkal'-- III X, Alay III IV, Zeravshan III K) were studied by us in more detail with the help of ground and helicopter observations, mainly by the profile 71°30' e.l., roughly from the Chatkal' depression ( III X) in the north to the high piedmonts of Alay in the south and the Alay hollow ( III V). Together with the analyzed TV image a set of other different-scale photographs was used.

The main results from the comparison of the different-scale images are presented in table 3. In addition to an increase in the detail of the distinguished targets as the scale got larger, one should note the different expressiveness of the geomorphological borders: primary and secondary.

The first were traced on the images of all scales, regardless of the zone of the spectrum, for example, the border of the nival and mid-mountain region of the Alay ridge and the Fergana depression, the border of adyry\* and oases of Fergana, borders of oases and sands. By having a different geomorphological rank, they nevertheless are sufficiently physiognomic in light of the sharp contrast in tone characteristics.

\*Translator's note: adyry--low foothills bordering Fergana depression.





The secondary borders correspond either to lower orders of the geomorphological rank (for example, variously lithologically expressed mountains or genetic types of plains) or less physiognomic (for example, border between proluvial cones and adyry).

The interpretation signs of the geomorphological targets in different zones of the spectrum were examined in the examples of three types of relief according to larger scale aerial photographs (1:100.000).

The limestone, average high-altitude ridge of the axial zone of Katranto (indices 4 a, b in table 3) is distinguished by a deep but thin erosion breakup. The greatest number of details in the relief are traced in the zone 0.4-0.45 mcm, where one can detect individual elements in the occurrence of the rock masses, limestone benches, boulder-pebble bed and so forth. The interpretability somewhat decreases in the zone 0.5-0.55, while in the zones 0.6-0.68 and especially in the zone 0.72-0.82 mcm the processing of details is the lowest. Analysis of the available literature advances the same conclusions. Photography in zones close to the ultra-violet section of the spectrum is the most informative for recognizing the carbonate rocks on the background of others since the first have a relatively high reflecting capability (Cronin, 1968; Del Bono, 1971). Photography under conditions of low lighting is especially effective (morning). This can be traced in the comparison of the interpretability of two images 6/13/1973 4 hours 37 min. and 6/14/1973 7 hours 30 min.

Volcanogenic-sedimentary mid-mountains (index 4 c, d) are most effectively interpreted in the zones 0.5-0.55 and 0.6-0.68 mcm, where the greatest number of details are traced (structural triangles, structural ridges with the dominance of a grey tone). In the zone 0.4-0.45 mcm. a darkening of the tone occurs (to dark grey) which is related to the low reflecting ability of the effusive complexes. In the zone 0.72-0.82 mcm, on the contrary, there is a lightening of the tone to lightish grey due to the somewhat-greater moisture content as a result of the increased improvement in land by silt deposition in fissures.

Similar to limestone mountains are the interpretation signs of low-mountain ridges covered with loess whose surface has a high reflecting ability. The most informative is the interval 0.5-0.68 mcm. in which a clear tracing is made of the illustration and nature of the breakup and the different-age rock masses of neogen and quaternary age are distinguished (grey and pale yellow bacterium). In the interval 0.4-0.45 mcm in light of the high reflecting ability, the loess has a light grey tone, the contrasts disappear between the surface of watersheds and the bottoms of ravines. Somewhat

(Table 3 covers two pages)

TABLE 3  
COMPARISON OF THE RANK OF INTERPRETED GEOMORPHOLOGICAL TARGETS ON DIFFERENT-  
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Regional names			Scale of image	1:10,000,000 /172
			Type of morpho- structure and morphosculpture	
Alay ridge	Upper Alay	Central Alay	1. High mountains on Paleozoic base with glacial-nival morphosculpture 4000-5300 m	Tree-like illustration Tone VI-VII
		North Alay	2. Average high-altitude mountains on Paleozoic base with erosion-denudation morphosculpture 2300-4000 m	Illustration
	Piedmont Alay	Okhmin depression	3. Intermontane neogen depression with arid morphosculpture 1500-2300 m	linear
	Ridge	Katranto	4. Average high-altitude mountains on Paleozoic limestones with arid denudation morphosculpture 1300-3600 m	Tone II-III
Fergana depression	Fergana	Ak-kap-chagai cone	5. Piedmont proluvial arid Pleistocene plains 400-1300 m	Structureless illustration
	Upper	Chimi-on adyr	6. Piedmont denudation arid ridges on neogen anticlines (adyry) 450-700 m	Tone VI-VI
	Fergana	Altyaryk oasis	7. Accumulative plains of peripheral irrigated section of depression (loam) 400-450 m	Indistinctly-spotty illustration Tone II-III
	Low-land	Kara-Kalpak steppe	8. Accumulative plains of central section of depression (sandy) 350-400 m	Structureless illustration, Tone IV-V
			Breakup (number of sections)	5

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## SCALE TV-IMAGES ACCORDING TO PROFILE OF AIAY -- FERGANA

Compiled by S. M. Aleksandrov, 1975

1:2,000,000	1:1,000,000	1:100,000
Tree-like illustration Tone V-VII	Tree-like illustration Tone VI-VII	
Linear-branching illustration Tone II-IV	Linear-branching illustration: glacial trough-like--Tone III-IV fledgling--Tone II-III	Outside the limits of flying
Linear illustration Tone IV-V	Linear illustration Tone IV-V oasis--II-III	
Linear illustration: limestones Tone III-IV	Linear-fledgling: limestones Tone IV	dislocat. limest. I-IV 4a sheet limes. breccia II-IV 4b
vulcanites Tone II-III	vulcanites Tone II-III	sediment. rocks III-V 4c
	blend Tone III	volcan. rocks II-IV 4d blend III-V 4e
Spotty medium-grainy illustration Tone IV-V	Indistinctly spotty fine- grained illustration Tone IV-V	boulder strongly broken up II-VI boulder-pebble broken up III-V loam lightly broken up III-IV
The same Tone V-VI	The same Tone III-VI (depending on zone of spectrum)	neogen-early Pleisto- cene strong, broken up II-V Pleistoc. medium broken up III-IV
Indistinctly spotty fine- grained illustration Tone I-II	Fine-grained spotty illustration Tone III-V	Sloping part of cone II-V light. slop. part III-IV flat part of cone III-IV
Grainy illustration Tone V-VI	Spotty fine-grained illustration Tone IV-VI	Anchored sands III-IV scattered sands V-VI
8	10	>15 (hypothetically-20)~

similar, but with a darkening of the tone to darkish grey is characteristic for the zone 0.72-0.82 where the contrasts are also leveled.

The zone of ophiolites and blends described by G. I. Makarychev and N. A. Shtreys (1973, 1974) (4e) is characterized by diverse combinations of structure and relief. It is very characteristic, for example, to have a combination of serpentinites (dark tone) of low resistance to denudation and jasper occupying the tops of cone-shaped hills (light grey tone).

Analysis of the information content of various zones on a small-scale TV image indicates that for the plain section of Fergana the zone 0.6-0.7 mcm is the most promising. In this range adyry, oases and sands are distinguished while in the zone 0.8-1.0 mcm all the plains have the same tone (V-VI).

#### Certain Conclusions

1. Analysis of the different-scale TV images permits separation of different-order, different-age morphostructures and the largest morphosculpture complexes (table 3).

2. Of the general laws one should note the noticeable lightening in the tone of mountain structures from the north to the south which is especially visible in the zone 0.8-1.0 mcm. This can be explained by two reasons.

a) from the north to the south due to the general aridization (Frontier Asia, 1956; Titova, 1973) there is a reduction in the role of the wood-bush vegetation, nut forests, forests of tyan'-shan' spruce, etc. (and the role of upland xerophytes increases) (Astragalus, Andropogon et al.) with the participation of xerophytic thin forests and subtropical steppes.

b) from the north to the south, from the region of Paleozoic folding to the region of Alpine belt, there is a natural replacement of volcanogenic (dark colored) rocks by more light sedimentary ones.

3. Analysis of the TV image also raised a number of problematic questions:

a) if the darkening of the north Kyzyl-Kumy is related to outcrops of iron accumulation sands, then why is this not observed in Zaunguz Kara-Kumy?

b) what explains the diffuseness of the northern border of Parapamiz and the lack of clear interpretation signs of Badkhyz and Karabil'?

c) how to interpret from the position of dynamics of the shift in lithospheric plates the complex mountain block of Karakorum, Kyen'-Lun' and the Himalayas and why does the illustration of the block Himalayas differ little from the illustration of the folded Karakorum?

d) what explains the somewhat greater volume of glacial-nival zone and how is this shown in glaciological works? By the optical effect?

e) to what is related the lack of interpretation signs of the large Ural-Oman lineament which is traced well in the region of the junction of Central Afghan massif and the fold of Iran on the territory of the Turan platform.

In addition it is necessary to explain the actual importance of different zones /175 of the spectrum in the interpretation of territories with different moisture conditions. For this it is necessary to extensively use the hydrogeological data and the field determination of moisture.

4. The information content of the TV image was compared with maps of the morphostructure and morphosculpture FGAM, according to the foreign territory on a scale 1:40,000,000 mcm, according to the territory of the USSR on a scale 1:15,000,000.

a) on the map of the morphostructure of Asia, for example, under the index MA-1 are united the folded high mountains and medium mountains (Serkhed, Makran, Suleymanovy mountains, Parapamiz, Bandi-Turkestan). Analysis of the TV image reveals the possibility of differentiating the mountain systems. Thus Parapamiz and Bandi-Turkestan to the north of Gerirud fault due to the extensive development of the leveling surfaces have a sharply distinctive illustration and phototone. Under the index M-9b are isolated the high upland plains of the middle massifs. The TV image permits differentiation of the territory of the middle massif, separation of the local elevations (ancient nucleus), hollows with different morphosculpture, etc.

b) on the map of the morphostructure and morphosculpture of the USSR under the index MN-6 are distinguished the high mountain ridges of the North and West Tyan'-Shan', MN-8--piedmont, MN-9--plains. The TV photograph permits isolation of ancient and young ridges, different types of plains, etc.





5. Analysis of the different tones agrees with the conclusions on the results of a comparison of spectral ranges of ERTS (Kondrat'yev et al., 1973).

The TV image in the interval 0.6-0.7 mcm is more informative for studying the relief and the geological structure, vegetation (valleys and oases), in the interval 0.8-1.0 mcm--for studying the open water surface. In a number of cases, due to the greater contrast, the image in the zone 0.8-1.0 mcm allows more clear interpretation of the contours of folded systems, for example, the mountains of Afghanistan.

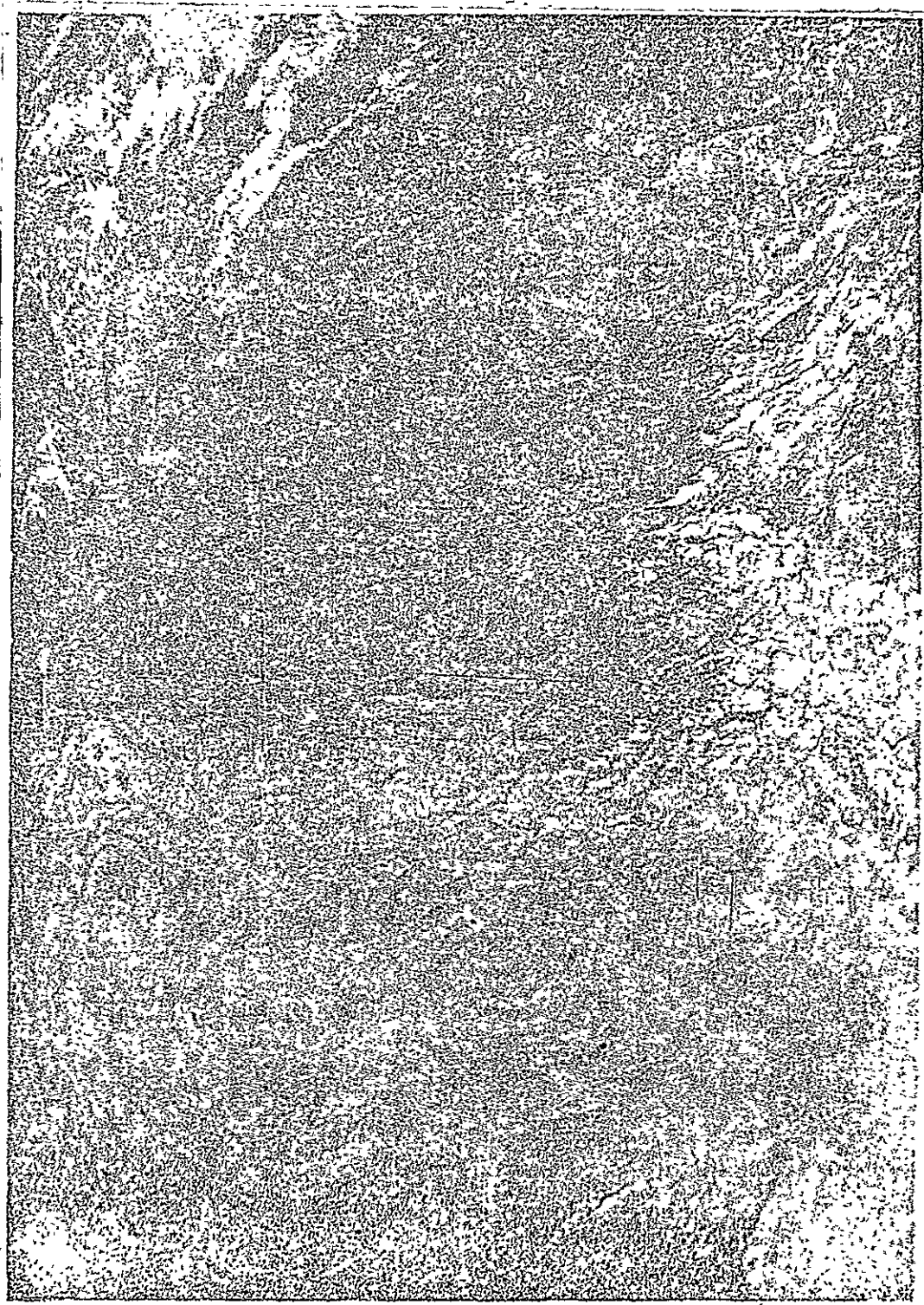
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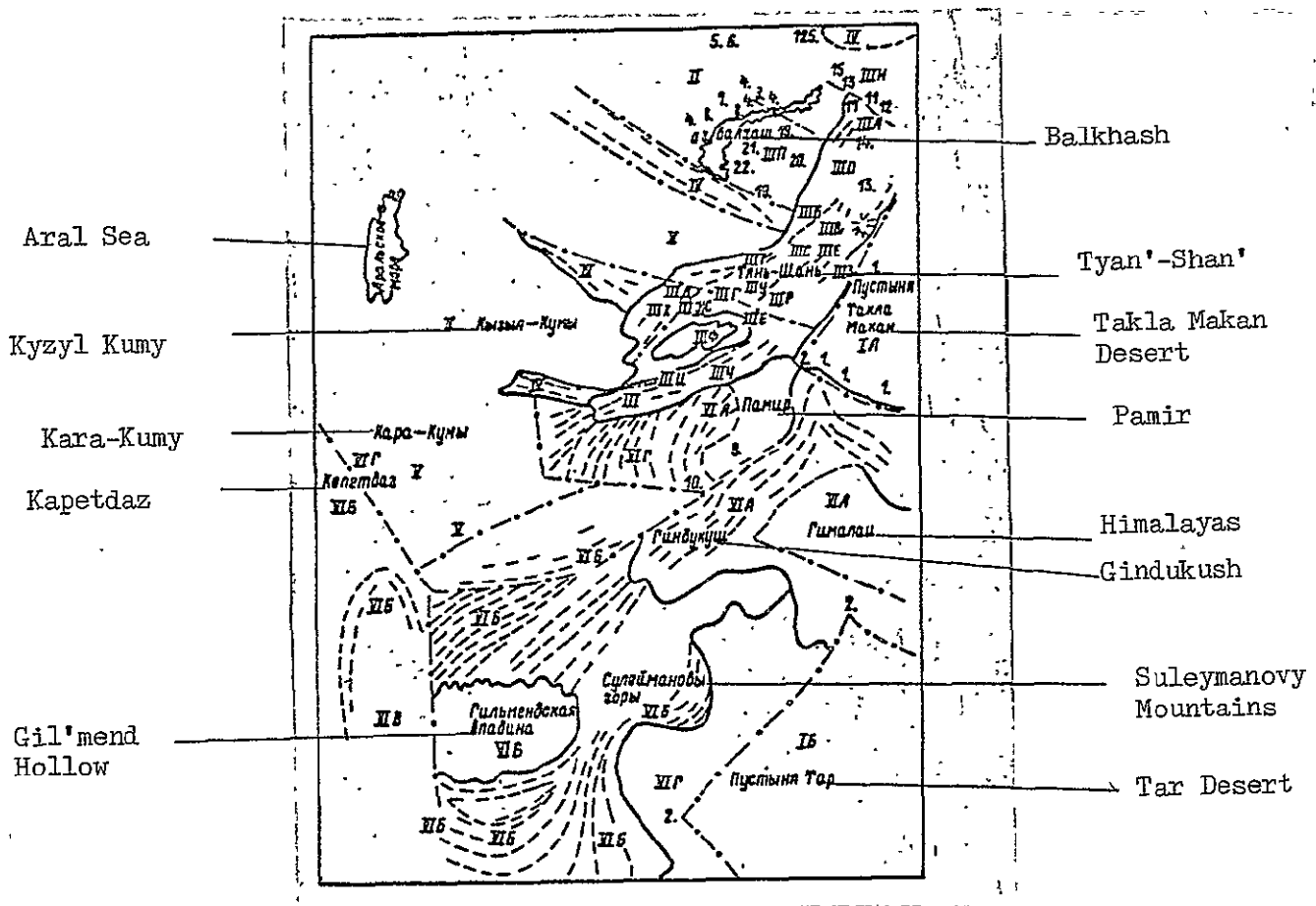


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Fig. 1. TV image obtained from AES system "Meteor", August 21, 1974 at 09 hours 32 min. Moscow time (zone 0.6-0.7 mcm).

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


-  Borders of morphostructure
-  Faults
-  Course of structure

Fig. 2. Schematic diagram of interpretation of TV image from August 21, 1974.

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PART III

METHODS

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Space Surveying in the Study of Natural Resources

Yu. F. Knizhnikov and V. I. Kravtsova

In the period under consideration investigation of natural resources by means of space technology has continued to be regularly developed. The most important events of the year are the launch of the orbiting scientific station "Salyut-III," the flight of the spacecraft "Soyuz-14," "Soyuz-15," and in December — a modernized "Soyuz-16," launched in preparation for the joint Soviet-American "Soyuz-Apollo" program which specifies experiments to study the environment. For the United States this 1975 flight will be the last manned flight planned in the current decade (20). This year will see the completion of the program of studies by the American orbiting station Skylab.

The seventeenth sputnik in the "Meteor" series, launched in the summer of 1974, carried a multiband scanner to obtain images of the Earth's surface. The survey covered large areas of the Soviet Union and adjacent regions — Europe, the Near East, India and Tibet as well as Antarctica. Sets of zonal black-and-white photographs are operatively transmitted to Earth for visual identification for evaluation and practical utilization.

February, 1974, saw the end of the 271-day work program of the orbiting station Skylab, which cost 2.6 million dollars (40). A relatively modest amount of time (101 hours) was set aside to study natural resources. Over 46 thousand pictures were taken of regions primarily on the American continent. There are dozens of publications concerning the instrumentation and tests aboard the Skylab station,

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but no substantial works have appeared on evaluation or utilization of the pictures obtained, although a symposium on the results of the Skylab program was held in 1974 in the United States.

A great amount of research, reflected in hundreds of foreign publications, has been devoted to work with photos from the American resources satellite ERTS, launched in July, 1972. Until early 1974, receiving stations in the US, Canada, Alaska and Brazil received 200 thousand photos from ERTS, completely covering the territory of the United States and three fourths of the land area of the Earth (5).

Photographs from the ERTS satellite have been very widely advertised and actively disseminated both in the United States and throughout the world. The Federal Government created a special Joint Committee for these purposes. Sales catalogs of ERTS photos were published and special bureaus opened in 30 cities for their distribution (5). In 1973, 1 million dollars of photos was sold. US petroleum companies alone bought 45 thousand photographs. ERTS photos are used in many countries on the American continent, Europe, India and a number of developing nations where they often provide basic information for mapping natural resources. A number of foreign publications have presented interpreted ERTS photographs in a scale of 1:1,000,000 or larger of Soviet territory, for example, regions of Leningrad, Vladivostok, Arkhangelsk, Surgut and Novgorod, which show such objects as the main Moscow-Leningrad railroad line (15, 23).

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NASA provides its customers with transformed contact (scale 1:3,369,000) and enlarged (scale 1:1,000,000-1:250,000) black-and-white zonal and color enhanced ERTS photos. Original photographs are transformed into a standard universal transverse Mercator projection, especially developed for the ERTS project. The geometric accuracy of the photos obtained by MSS scanner is characterized by errors: after preliminary analysis - 400 m, after exact analysis - 100 m (13, 30).

1974 is the year of mass analysis of ERTS photos. It is being conducted in the United States by numerous branch organizations and universities under contract to NASA. Three ERTS conferences were organized especially for discussing results of this analysis (5). These results were also reported to other large forums.

With the huge variety of uses for these photos, it appears that their basic application is in compiling various thematic maps because of their sufficiently good

resolution, high informational value of color enhanced photos, complete coverage of territory and the fact that the system of analysis specifies conversion of the image to cartographic projection. ERTS photos in essence already are prepared photomaps which can be used to solve many problems. ERTS photos have been used to compile mosaic photomaps of a number of states, used by their administrations for monitoring and planning. For the first time in history a photomap was created of the entire United States and Alaska. A montage of photomaps of the US from 595 photos in a scale of 1:1,000,000 was produced in 5 months, its cost — 65 thousand dollars (21). For practical purposes — to assist state administrations — so-called land use maps are being created. A method of automated recognition of certain categories of lands is being developed based on analysis of the density of zonal images. In this way, 22 categories of land use can be isolated on maps — water, forest, agricultural lands, roads, towns, etc., producing digital or colored maps, as was done, for example, for California (35) and other regions of the US. The previously suggested automated composition of operative agricultural maps with recognition of crops on photos and determination of their condition on the basis of differences in density of zonal images has not yet been put into practical use.

With the appearance of ERTS photographs, efforts using photos to study shorelines and ocean areas were significantly expanded. In this direction, multiband surveying gives the greatest effect. Studies on its use are directed toward the investigation of landscapes, primarily vegetation, flooded lands — marshes — for which automated mapping methods are used (36). The varying depth of penetration of solar rays in different wavelengths opens up the possibility of using multiband photos to determine depth, true, only in the shallow-water zone. In the area of the Bahama Bank it was possible to show isobaths of 2, 5 and 10 m on ERTS photos. Another extremely important practical direction is study of the biological productivity of the ocean. Nature observations accompanying the ERTS survey showed that photos can be used to study biological resources of the sea if the chlorophyll content is over  $0.1 \text{ mg/m}^3$  (47). ERTS photos are also being used to solve a number of other oceanological problems: determining the limits of the Loop in the Gulf of Mexico, studying the movement of water in Alaskan estuaries, recording tidal waves in New York Harbor, determining the boundary between fresh and salt sea water on the Pacific sea-coast of North America (32), analyzing the distribution of suspended matter in the Potomac River (31). A number of works deal with fishing and the fishing industry (27) and ice conditions of seas (16, 23).

In other branches of geographic research ERTS pictures have been used primarily for mapping various components of nature — geological, permafrost, soil, geobotanical, etc., for which the use of synthesized color photos is recognized as most effective. The use of zonal images in studies of natural components of the Earth's surface is effective only in isolated, although extremely important cases — for example, in studying the composition of rock and surface deposits. Photos in the 0.6-0.7 micron band were used to detect iron-rich rock in the Appalachians (35). The color of rock has also been used to locate nickel deposits in Western Canada and copper in Pakistan (21).

The Canadian Forest Service conducted a broad complex of studies on forest taxonomy by interpreting ERTS photos of British Columbia, Alberta and the environs of Ottawa (44). ERTS photos in various spectral zones were not effective for studying the rock composition or taxonomical characteristics of forests. Only types of forests in a general shift of ecological conditions are distinguished; isolation of age groups of forests is possible only in 20-30 year intervals. At the same time, multiband photos do show various damage to trees — cuttings, centers of insect and disease damage, damage by frost and SO<sub>2</sub> fumes.

We must also note that ERTS photos give interesting material for studying other aspects of environmental pollution. It is sufficient to indicate the detection of mine dumps in South Africa (24), observations of refuse dumping areas and widespread pollution in New York harbor (45) and the detection of oil slicks on the surface of the ocean (42). Although the great possibilities of space technology for solving ecological problems on a global scale are noted, no significant practical works in this area have yet appeared.

Works on the application of multiband surveying in the Soviet Union are progressing as a whole in the same directions; manifest areas of its effective utilization are similar — agriculture, study of the composition of surface deposits, particularly, the salination of soil-forming rock and integrated study of ocean areas. True, publications on multiband data appeared only on the latter question in 1974. Photos from the spacecraft Soyuz-12 of the shallow-water zone of the Caspian Sea made it possible to distinguish the image of underwater vegetation and various forms of bottom relief and compile a map of the underwater landscape of the shallow-water area (7).

Comprehensive studies conducted in our country on space survey data have been reflected in publications on complex geographical interpretation (11); however, the main mass of publications consists of geological works. Geologists are now the main users of space photographs in our country. Geological organizations are converting to extensive practical creation of photo-geological maps from space photographs, feeling that the new method of mapping regional geology makes it possible to reduce the cost of making geological surveys, updating and compiling composite geological maps 15-20% and speeds up these works 1.5 times (2). The use of space photos has forced reconsideration of views on the geological structure of large regions of the country, including those considered well-studied. This was aided at first by the enforced use of weather satellite television pictures for geological purposes (1). Their montages — telephotographs — helped establish the important role of large deep breaks in the Western Siberial lowland which redefined directions for further oil and gas prospecting efforts. Photographic surveys also gave completely new information on breaks in accumulative plains such as the Southern Balkash lowland. Photos were used to establish the block structure of Rudniy Altay, making it possible to evaluate correctly prospects for discovering new deposits of lead and zinc. Previously unknown faulted and plicate structures, including prospects for petroleum and gas, were found in regions of Mangyshlak and the Ustryurt plateau. A distinctive feature of the studies of Soviet geologists is their methodological direction, their in-depth analysis of methodological questions (9). Successfully using not only photographs, but also television pictures (1), Soviet geologists have advanced a number of new theories — on increasing the "depth" of studies with conversion and smaller scale and summary images (9); on "levels of generalization," that is, obtaining qualitatively new information from photos by changing their scale 4-5 times (2). /182

Although in no country have space photos yet become the main basis of commercial cartography on a nationwide scale, it is now clear that in the future the main direction of their use will be the area of thematic cartography. The advantage of space photos is primarily in operative gathering of comparable information for vast territories. The majority of the many practical uses of space photography already lead to a cartographic finale. Publications give many examples of updating and correcting existing maps, especially in developing countries and Arctic regions (41). But the main value of space photos is in their use as a source and basis for various thematic maps in scales of 1:2 million-1:10 million, and in the future in a scale of 1:200,000 (43). Photo maps compiled from photographs are receiving ever broadening distribution.

Multiband surveying, as was supposed (43), is now the main kind of surveying conducted for studying natural resources. We must note that in the great and varied practical application of space photos the effect of multiband surveying appears only in individual cases. No significant results have yet been obtained from multiband surveying in the area of automated interpretation, although intense studies are being conducted in this direction (29).

In space surveying the screening effect of clouds was a more serious problem than first anticipated. The cloud coverage of the Earth's surface not only limits the possibility of obtaining pictures in the required regions, but also reduces the effectiveness of satellite cameras 50-70% (19), affecting the completion of planned programs in manned spacecraft and orbiting stations. The most favorable regions for surveys are North Africa, Mexico and Central Australia, the least favorable are Antarctica and the belt along the Tropic of Capricorn. The Soviet Union, countries of Western Europe and North America fall into medium conditions.

Besides the light range of electromagnetic fluctuations, works are actively being conducted on the use of the nonphotographic zone for surveying, especially urgent in connection with the above indicated problem of cloudiness. Infrared and radiothermal surveying make it possible to record thermal zones on the surface of the sea and land, to create heat maps of volcanoes and record the light of cities, forest fires and burning gas waste at night (15). IR-photos from Nimbus-3 revealed pollution of coastal waters (without determination of the kind of pollution) in Northern European seas (28). The advantage of using a small window (3.4-4.1 micron) in comparison with a large one (10-12 microns) has been noted. Microwave surveying from the Nimbus-5 satellite, the first equipped with a transmitter operating in the 1.55 cm range, gave a picture of the distribution of perennial and annual ice in the entire Arctic Ocean (16). This kind of sensing is used to study ocean waves and soil moisture (3, 38). A number of publications (8, 34) have pointed out the prospects for using all-weather radar surveying in a complex of aerospace methods. /183

Spectrophotometry of test objects also sometimes serves as a supplement to satellite surveying. For example, establishment of a connection between the reflective capacity of Central Asian deserts and the ground mass of pasture vegetation makes it possible to estimate the productivity of pastures by the density of their image on television pictures from Meteor satellites (10).

Surveying from airplane laboratories has become a component of studying natural resources by space methods. Airplane experiments are set up to develop methods and equipment for space sensing, but they are frequently also of independent value. Beginning in 1973, a number of departments in the Soviet Union have been conducting surveys of test sites from airplane laboratories (12). New AN-30 airplanes have been used as flying laboratories.

Although the main launches of space equipment for obtaining initial data are being carried out in two countries -- the USSR and the USA -- many nations are conducting methodological studies, in particular, airplane experiments. Especially active studies on a method of identification are being conducted in France, where surveys are made not only from airplanes, but also from air balloons and aerostats (25). Surveying from experimental rockets also has not lost its value.

Study of the Moon and planets according to previously planned programs is being continued. The experimental laboratory on the Moon -- Lunokhod 2 -- has ended its work, the station Luna-22 carried out surveying from circumlunar orbit. Noteworthy is the appearance of joint Soviet-American programs, for example, on creation of a general complete map of the Moon in a scale of 1:5 million. Actively being continued are efforts to map Mars, primarily on the basis of Mariner-9 data, which are being used to create maps in a scale of 1:5 million, 1:1 million and 1:250,000, as a whole forming a Mars Atlas as well as a Mars globe (14). Cartographic efforts should be aided in studies of the surface by the launch of Viking, planned for 1975. In 1974 Mariner-10 first surveyed the surface of Mercury. Flights are beginning to distant planets; for example, Pioneer-11, flying past the planet Jupiter, first transmitted to Earth an image of its polar regions; in 1979 it should approach the orbit of Saturn.

International cooperation in space research is expanding, particularly in investigation of the natural environment by space means. Besides the well-known joint Soyuz-Apollo flight program, other series of international programs have been carried out ("Tropex," "Iceberg"). In April, 1974, the regular Soviet-American meeting on study of the environment by space means was held in Washington. The regular XVII session of COSPAR was held in Brazil.

Works on the use of space methods to study the natural resources of the Earth and planets are widely covered in the press. Besides publications in special jour-

nals and annuals (the number of publications passing through the Abstract Journal of VINITI in 1974 alone was over 1 thousand), we must indicate the annual volume of material from thematic conferences and symposia. In 1974 were published the Works of the IX Michigan symposium (37), the COSPAR symposium on the use of space methods for Earth sciences in Constance, FRG (18) and the first Pan American symposium on remote methods (26). For broad readership, the publication of albums of space pictures is very important. Such albums of ERTS pictures were published in the United States (39). The fine regular publication of the book "Kosmicheskiy obzor Zemli" (A space view of the Earth) with a large new set of photos, primarily from ERTS and Skylab, an identification key and popular-science type text was published in the FRG (15).

In this country the number of publications lags significantly behind the Americans, but review and generalized works (4) and works on a broad methodological scale continue to appear. Publication has begun of a series of thematic collections dealing with study of the natural environment by space means according to data of Soviet-American cooperation (6). The geological use of space methods, as in previous years, is dealt with in a special edition of the journal, "Izv. vuzov. Geologiya i razvedka," No. 12. /184

In all countries the problem of training specialists to interpret space photographs continues to be acute.

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D. S. Bulatov

At the present time, with the appearance of multiband scanners, real prospects are opening up for automation of the process of recognizing objects in remote airplane or satellite observations. Automation is based on recording the values of reflected or radiation energy in several previously selected spectral bands with further computer analysis of the data. The question arises of the number of different classes of objects which can be recognized and of the accuracy (or probability of error) of recognition. Modern scanners, scanning the observed surface, receive information from elementary areas in several instantaneous viewing angles. With highly accurate identification of such elementary areas with one of the known classes of objects, contours of features can be identified quite accurately and, therefore, areas occupied by such features can be determined. However, as will be seen from the following, such highly accurate identification narrows the total number of recognizable classes of objects. If the limits of objects are known a priori (for example, by means of contour identification of aerial photographs), and only the content is unknown, then elementary areas can be recognized with relatively low accuracy, which significantly increases the total number of separable classes. In fact, if some uniform feature was quantized into a sufficient number of elementary areas and in 70% of cases we found that it was wheat and if false identifications of the area were scattered chaotically within the selected feature, it is safe to say the the entire feature is indeed wheat.

In order to establish how many classes of objects and with what accuracy can be identified, let us briefly consider statistical recognition.

#### Statistical recognition

Let us consider the assignment of individual objects to one of the previously selected classes according to their optic properties (reflection or intrinsic radiation of energy). By individual object we shall in the future mean an elemen-

tary area, the size of which depends on the resolution of the scanner. In principle such individual objects differ from each other in their optic properties. At the same time, a number of individual objects can have similar or even identical optic properties. The presence of such similar properties makes it possible to group objects into several classes. Classes can be of varying degrees of generality, for example, by one class we can mean one field of wheat or we can mean all fields of wheat in a given region, etc.

Let us take  $M$  classes. We designate them as  $B$ , where  $B = 1, 2, \dots, M$ . Objects, and this also means classes, are characterized by a certain set of signs.

In our case, the signs are identical for all objects and represent energy recorded by the scanner in given spectral bands, i.e. the number of signs is equal to the number of bands. Let the number of bands be  $N$ . Let us designate values of signs in the selected bands as  $X_i$ , where  $i = 1, 2, \dots, N$ . Each object will be characterized by a certain set  $N$  of numbers. Let us designate such a set as  $b_t$ , where  $t$  can take any value of the total number of objects.

Each sign can take any value within limits of possible change. If we have in mind values of reflected energy, then the limits of change in the sign correspond to the limits of possible change in reflection coefficients which lie in the interval from 0 to 1. Therefore, we will consider that values of signs  $X_i$  also lie in this interval. The interval of change in actual energy values recorded by the scanner can always be reduced to this interval by the introduction of the appropriate proportionality factor.

For selection of specific classes; values of  $X_i$  need not occupy the entire interval from 0 to 1, but a part of it  $\Delta X_i = X_{i_{\max}} - X_{i_{\min}}$ .

Each class includes a certain set of individual objects. Different objects of one class have similar values of  $X_i$ , but these can differ slightly from each other as factors affecting them vary with transfer from one object to another. The probability approach (1) is used to describe such classes. Each class is characterized by multidimensional density distribution of probabilities  $f_i$ . Such functions can be constructed for each class or for the entire set of objects of a given class or for a certain representative sample. Besides multidimensional densities of probabilities, a priori probabilities of classes  $P(B_i)$  are also introduced, showing how

5  
4  
3  
2  
1

often a certain class is encountered in actual conditions.

The distribution of specific objects by classes is based on the Bayes method of calculating a posteriori probabilities. In accordance with this method, the probability of the hypothesis of a given object belonging to each class is determined according to the formula:

$$P_i(B_i/b_t) = \frac{P(B_i) f_i(b_t/B_i)}{\sum_{i=1}^M P(B_i) f_i(b_t/B_i)} \quad (1)$$

where  $P_i(B_i/b_t)$  — a posteriori probability of the hypothesis of t-object belonging to i-class  
 $f_i(b_t/B_i)$  — density distribution for t-object, assuming it belongs to i-class.

A posteriori probabilities of hypotheses are determined for all M classes and this distribution is used to decide to which class a given object belongs. We shall consider a determining plan, identifying a specific realization with that class for which a posteriori probability is maximum. Such a procedure provides minimum mean error of recognition (1).

With the use of the Bayes method for recognizing classes of objects, density distributions are constructed for each class according to a certain representative sample. Thus, if we want to recognize M classes, we would have to have a minimum of M key sections for instructional purposes, i.e.  $f_i$  functions are plotted. We must have available information on what is in the selected keys at the time of the survey. The use of the Bayes method gives us the possibility of identifying all objects in a studied region with classes whose description is given in selected keys.\* Thus, the use of a scanner together with a computer opens the way to automation of the process of recognizing objects.

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\*In this article we are not considering the question of selection of keys, which must be sufficiently representative. But we must acknowledge that this approach makes it easy to find criteria of the accuracy of key selection.

For a theoretical evaluation of the number of recognized classes and the accuracy of recognition, let us make several assumptions. First, let us assume that all considered classes are found with the same frequency. Such an assumption, without changing the generality of conclusions, simplifies analysis. Second, let us assume that density distributions of probabilities of parameters  $X_i$  for all classes are subject to normal law. In this case plotting of  $f_i$  amounts to finding average values of  $X_i^i$  and plotting of a correlation matrix, and in the absence of correlation - to finding mean quadratic deviations  $\sigma_i$ . Third, let us assume that  $\sigma_i$  are constant for different classes and do not change with transfer from one spectral band to another. Let us determine how many classes we can recognize and with what accuracy. Let us consider first a one-dimensional case when recognition is conducted in one spectral band (see Fig. 1). This illustration shows density distributions  $f_i$  for all adjacent classes; average values of  $\bar{X}_i^i$  are located the same distance from each other.

Evidently, all individual objects belonging to the second class, but having values of  $X_i$  lying to the left of point  $X_{10}$  or to the right of point  $X_{10}$  we will erroneously assign either to the 1st or 3rd class. Recognition errors are calculated as follows:

$$\zeta = 1 - \int_{X_{10}}^{X_{10}'} f_2(X_i) dx_i = 1 - \left\{ \Phi\left(\frac{X_{10}' - \bar{X}_1''}{\sigma}\right) - \Phi\left(\frac{X_{10} - \bar{X}_1''}{\sigma}\right) \right\} \quad (2)$$

where

$$\Phi(X) = \frac{1}{2\pi} \int_{-\infty}^X e^{-t^2/2} dt \quad - \text{function of errors}$$

As  $X_{10}' - \bar{X}_1'' = \Delta/2$  и  $X_{10} - \bar{X}_1'' = -\Delta/2$ , after simple conversions we have:

$$\zeta = 1 - \left\{ 2\Phi\left(\frac{\Delta}{2\sigma}\right) - 1 \right\} \quad (3)$$

According to formula (3) with a given  $\sigma$  it is easy to find value  $\Delta_1$  for any value of  $\zeta$ , i.e. the minimum distance between average values, providing error of recognition no more than  $\zeta$ . Knowing the minimum and maximum possible value of  $X_i$ ,

it is easy to calculate the number of classes  $L_1$  recognized with given error  $\zeta$ .

$$L_1 = \frac{X_{1 \max} - X_{1 \min}}{\Delta_1} = \frac{\partial x_1}{\Delta_1} \quad (4)$$

Figure 2 illustrates cases of two-dimensional recognition for five adjacent classes. Average density distributions are located the same distance  $\Delta_2$  from each other. For this case, recognition error in the absence of correlation between bands is;

$$\zeta = 1 - \left\{ 2\Phi\left(\frac{\Delta_2}{2\sigma}\right) - 1 \right\}^2$$

Correspondingly, for the N-dimensional case, in the absence of correlation between all N bands, we shall have:

$$\zeta = 1 - \left\{ 2\Phi\left(\frac{\Delta_N}{2\sigma}\right) - 1 \right\}^N \quad (5) \quad /190$$

Here the number of recognized classes is:

$$L_N = \frac{1}{(\Delta_N)^N} \prod_{i=1}^N \partial x_i \quad (6)$$

Formulae (5) and (6) are obtained, assuming the absence of correlation between bands. In fact, such correlation does exist and is the stronger the more spectral bands we select. In fact, if we know X in K bands and if K is high enough, we can predict almost accurately the value of X in K + 1 band, i.e. the introduction of K + 1 band gives no additional information.

Thus, in order to distinguish the most classes, selection of a number and location of spectral bands must be based on two prerequisites: the least correlation of bands and the greatest values of spectral intervals  $\partial X$ .

Analysis of curves of spectral brightness ratios for agricultural objects in the 0.4-1.5 micron range (2-5, 9) gives basis for asserting that such uncorrelated bands will be no more than four or five. Works (6, 7) indicate the three most informative bands having centers with longwaves of 0.55 micron, 0.67 micron and 0.80 micron. The recognition of these bands indicates that, evidently, they will also be the least correlated, although this question requires additional study. To

these zones, based on the principle of least correlation, in our opinion, we must also add bands with centers at 0.4 micron and 1.5 micron, and possibly the band of inherent infrared radiation and the radar band. Analysis of curves of spectral brightness ratios of agricultural objects (2-5, 9) shows that for a limited spatial region values of  $\Delta X$  do not exceed the following levels: 0.4, 0.5, 0.3, 0.20 and 0.10; correspondingly for bands with maximums at 1.5 micron, 0.8 micron, 0.67 micron, 0.55 micron and 0.4 micron (we are considering bands of inherent thermal radiation and radar because of lack of data).

For these values of  $\Delta X$ , formulae (5) and (6) are used to calculate the number of separable classes depending on  $\sigma$  and  $\zeta$  (see Table 1).

Table 1

NUMBER OF SEPARABLE CLASSES DEPENDING ON ERRORS OF RECOGNITION  $\zeta$  AND NUMBER OF SPECTRAL BANDS SIMULTANEOUSLY USED IN RECOGNITION OF N

N	$\Delta X_i$	$\zeta = 0,01$				$\zeta = 0,10$				$\zeta = 0,25$			
		$\sigma$				$\sigma$				$\sigma$			
		0,005	0,01	0,02	0,04	0,005	0,01	0,02	0,04	0,005	0,01	0,02	0,04
1	0,4	16	8	4	2	24	12	6	3	35	17	9	4
2	0,5	256	64	16	4	525	131	33	8	890	222	56	14
3	0,3	$2 \cdot 10^3$	310	39	5	$6 \cdot 10^3$	810	101	13	$1 \cdot 10^4$	$1 \cdot 10^3$	196	25
4	0,2	$1 \cdot 10^4$	925	59	3	$5 \cdot 10^4$	$3 \cdot 10^3$	200	13	$1 \cdot 10^5$	$6 \cdot 10^3$	400	26
5	0,1	$4 \cdot 10^4$	$1 \cdot 10^3$	41	2	$2 \cdot 10^5$	$6 \cdot 10^3$	182	6	$4 \cdot 10^5$	$1 \cdot 10^4$	370	12

This method of recognition specifies the use of high-speed scanners. A scanner, like any measuring instrument, has its own measurement error. If maximum relative error of the scanner is  $t\%$ , then the mean quadratic deviation for the scanner can be estimated as

$$\sigma_{\zeta} = \frac{1}{3} \cdot t\% \cdot \bar{X}_i \cdot \frac{1}{100} \quad (7)$$



In order to measure accurately random values having mean quadratic deviation  $\sigma$ , the mean quadratic deviation of the instrument  $\sigma_z$  must not be more than  $0.25 \sigma$  (8), i.e.

$$\sigma_z \leq 0.25 \sigma \quad (8)$$

From formulae (7) and (8) we get a connection between relative instrument error  $t\%$  and  $\sigma$

$$t\% \leq \frac{75}{X_i} \sigma \quad (9)$$

The value of  $\bar{X}_i$ , averaged for all five ranges, is approximately 0.15-0.25 and, therefore, with  $\sigma = 0.005$ ;  $t\%$  must be not more than 1.5-2.5%. Modern scanners provide accuracy on the order of 2-3% (10-12), which corresponds to  $\sigma$  about 0.005; therefore, in Table 1 this value is also taken as minimum.

#### DISCUSSION

This model is, of course, only a certain plan, assuming the absence of correlations between values of  $X_i$  in different spectral zones and even distribution of classes in the spectral bands. In practice these requirements will be disturbed, which can reduce the number of separable classes. From Table 1 it can be seen that the number of classes depends on the value of  $\sigma$ . This value is given us by natural objects themselves, although it is immediately clear that it depends on the scale of the survey. Increasing the altitude of the survey with a given instantaneous viewing angle of the scanner reduces the area of the individual objects and, therefore, there is an optic generalization of values  $X_i$ , thereby reducing the value of  $\sigma$ . However, in order for statistical recognition to be possible, we must quantize a uniform feature into no less than 20-30 individual objects. Evidently, optimum selection of survey altitude, or at a given altitude -- the instantaneous viewing angle, will also give us the maximum possible number of recognizable classes.

The number of recognizable classes (see Table 1) depends on the required accuracy of recognition. Increasing error from 1% to 25% increases the number of recognizable classes approximately 5-9 times; even with high recognition accuracy, however, the number of classes is extremely significant.

From the table it can be seen that for all  $\zeta$ , with certain values of  $\sigma$  there is a "saturation" effect, i.e. lack of increase and sometimes even a reduction in the number of classes with increase in the number of bands used simultaneously in recognition.

In works (13-14) an attempt was made at automatic recognition of a number of objects. 5-8 objects were recognized with an accuracy of 80-90% (10-20% error); it is noted that accuracy of recognition is higher in the 3-4 optimum bands than in all 12. Work (14) gives values of  $\sigma$  for all zones for various objects; they range from 0.02 to 0.05. For these values of  $\zeta$  and  $\sigma$ , Table 1 also shows that the number of recognizable classes is not great and that the "saturation" effect occurs with increase in the number of bands above three or four. However, recognition in these works was conducted without optimization of the survey scale which, in our opinion, was also responsible for such scanty results. The features used for study and recognition were quantized into several hundred points. As we already noted, reduction of scale, and in connection with this — reduction of the number of individual objects, must lead to a reduction in values of  $\sigma$ . Reduction of  $\sigma$  two to three times, i.e.  $\sigma$  about 0.01, as seen from Table 1, causes a significant increase in the number of separable classes and, what is more, can eliminate the "saturation" effect, or more correctly, increase the number of bands giving additional information. In addition, in works (13-14), individual objects were recognized. In our opinion, recognition must be made of uniform features, giving limits of these features a priori, for example, according to data from contour identification of aerial photographs.

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### CONCLUSIONS

The above indicated agreement of our results with experimental data of works (13-14) leads us to assert that the model we considered corresponds quite well with reality. Therefore, this model, and in particular, the results given in Table 1, make it possible for us to predict a relation between the number of spectral bands, accuracy of recognition and number of recognizable classes.

The Bayes method of recognition which we discussed makes it possible with high-speed highly accurate scanners to identify various classes of objects on the basis of information obtained in studying previously-selected key sections. This is a suitable path to follow, as it makes it possible for complete automatic analysis of information according to a pre-set program, i.e. machine identification in the sense

of identifying the content of contours. This method gives us criteria for correct selection of key sections and survey scale. Conducting the survey at different times, using this method, we can easily select the optimum survey time for solving different problems. All these problems: selection of keys, scale and time of surveys are independently valuable. But, in our opinion, only a comprehensive approach will provide an optimum solution to the problem of automating the identification process.

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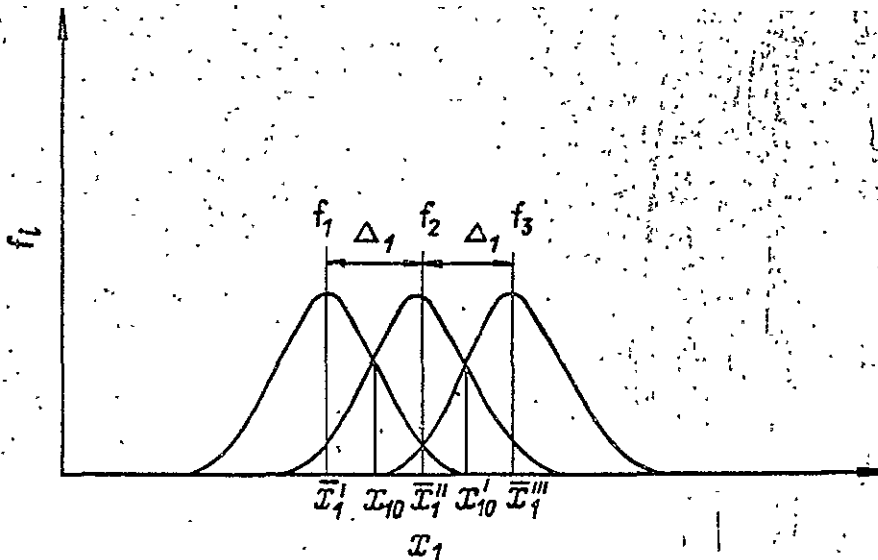


Figure 1. Recognition in one-dimensional case

$X_1$  - variable corresponding to energy recorded in selected spectral band  
 $\bar{X}_{1I}; \bar{X}_{1II}; \bar{X}_{1III}$  - average values of density distributions  $f_1; f_2; f_3$   
 $\Delta_1$  - distance between average values  
 $X_{10}; X'_{10}$  - points of intersections of distribution curves

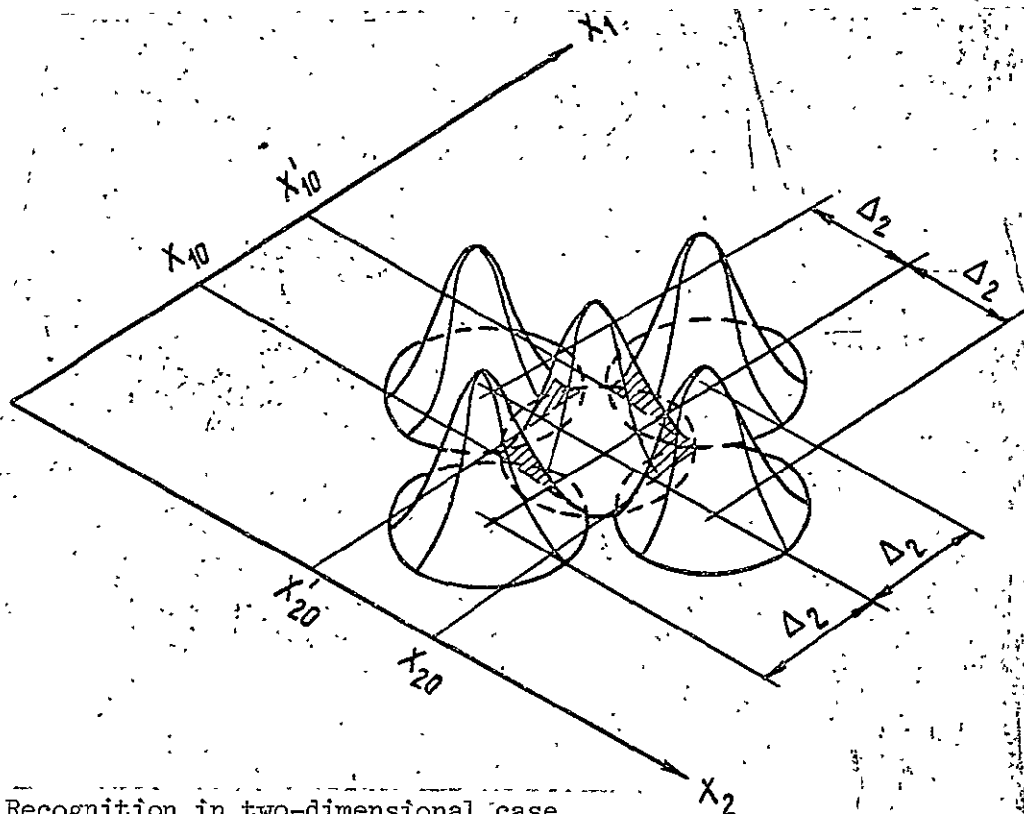


Figure 2. Recognition in two-dimensional case

$\Delta_2$  - distance between average values  
 $X_{10}; X'_{10}; X_{20}; X'_{20}$  - coordinates of density projections of the intersection of two-dimensional distribution functions on a plane  $(X_1X_2)$

DEPENDENCE OF SPECTRAL BRIGHTNESS RATIOS  
ON THE MOISTURE IN THE SOIL SURFACE

V. B. Malyshev, O. V. Kaydanova and D. S. Bulatov

In connection with the increasing importance of remote methods in studying the natural resources of the Earth, one urgent problem is in-depth study of the optic characteristics of natural objects. Knowledge of the dependences of these characteristics on factors affecting them will make it possible to identify natural objects by objective identification signs.

However, study of such dependences is difficult because varying factors act simultaneously and interact in a complex way with each other (1-3). Therefore, this necessitates field experiments to study the effect of individual factors with the greatest possible stabilization of others.

One of the factors having an important effect on optic characteristics of such natural objects as soil is its moisture content. Many authors have noted that moist soils have less total brightness than dry and with an increase of moisture, the course of the spectral curve of soils remains practically unchanged, but there is a reduction in total brightness (3-6).

Fig. 1 shows schematically the general pattern of reduction of soil brightness with increase of moisture. From this illustration it can be seen that with a change in soil moisture in the 0-1 interval, from absolutely dry to air-dry, brightness remains practically unchanged. The so-called gradientless range is specific for different soils. In the 1-2 interval, from air-dry to maximum hygroscopicity, a significant reduction is observed in the SBR. The greatest reduction of brightness occurs in the 2-3 interval, from maximum hygroscopicity to least moisture capacity. After soils reach least moisture capacity, reduction of brightness becomes insignificant (interval 3-4). Minimum values of soil brightness are evidently reached with complete moisture capacity. With further moistening, brightness in the visible band of the spectrum does not change markedly.

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We must also note that besides moisture, soil brightness is also seriously affected by such factors as mechanical composition and structure of the surface.

The purpose of our experimental work was to study the dependence of spectral brightness ratios (SBR) of soil on change in its surface moisture. We made such tests in June-July, 1974, in the southeastern part of the Belgorod Oblast in the Novo-Oskol Region. SBR measurements were made by a field spectrometer similar to the S-9 spectrometer (7), but its diffraction grid was replaced by interference light filters. This spectrometer operates in the 400-500  $\mu\text{m}$  wavelength range. Viewing angle was  $12^\circ$ . One cycle of measurements took 6-10 minutes. Spectrometry was conducted according to the usual method similar to that described by K. Ye. Meleshko. As a standard we used a barytic screen. Relative measurement error of SBR was determined by SBR measurement of unaltered test objects and is 3-5% for SBR of 0.2-0.3 and 15% for low SBR on the order of 0.05-0.10. All SBR measurements were made in clear sunny weather with winds at 1-1.5 m/sec. During one cycle of measurements, summary illumination and the ratio of total and diffuse illumination remained constant; this was monitored by a luxmeter. Our preliminary measurements showed that from 10 a.m. to 3 p.m. changes in the altitude of the Sun and the related change in illumination of the object have practically no effect on SBR.

During the experiment air temperature was 23-25°C. Soil temperature at a depth of 0.5 cm varied from 33 to 39°C, and at a depth of 5 cm - from 26 to 30°C.

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Our studies were conducted on flood meadow moderately loamy sandy soil in dry floodland of the Oskol River, formed on deluvial loams underlaid at a depth of 80 cm with alluvial sand. These soils, evidently, are in a stage of settling, as good differentiation of the soil profile is observed; there are no signs of stratification in the profile. A thick dark-gray humus horizon (A + AB = 67 cm) is distinguished by a pronounced granular structure.

In an unplowed field with a level surface, exposed to repeated natural precipitation, we selected six uniform plots measuring 1 x 1 m, located at a distance of two meters from each other. The surface of all plots was gray. Twenty four hours before spectrometry, plots No. 1, 2, 3 and 4 were spaded to a depth of 20-25 cm, leveled and raked smooth until a uniform surface was produced with aggregates measuring from 0.5 to 2 cm.

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As is known, moistening can change the structure of the soil surface and, therefore, SBR as well. Evidently such a change in structure of the soil surface appears most strongly on freshly plowed soil. In order to evaluate this effect, plots No. 5 and 6 were left in their natural state; due to natural moistening their surface was very smooth and covered with a crust 1-2 cm thick.

Plots No. 1 and 6 always had natural moisture, plots No. 2-5 were artificially moistened (Table 1) by watering cans held 1.5 m high with various amounts of water, calculated on possible precipitation in this area at the time: plot No. 2 - 3 mm; plot No. 3 - 5 mm; plot No. 4 - 10 mm and plot No. 5 - 10 mm (9). Soil samples were taken from the surface layer (0-0.5 cm) of soil in all plots five times to determine moisture. Moisture samples were taken before watering, immediately after watering, an hour after and four hours after watering. Spectrometry was conducted to determine moisture immediately after the soil samples were taken. Measurement of the moisture in plots for four hours is given in Table 1.

Table 1

CHANGE IN MOISTURE OF THE SURFACE LAYER OF SOIL IN EXPERIMENTAL PLOTS

Plot number	Amount of water used for watering in mm	Natural moisture (%)	Moisture of soil surface			
			Time of day			
			10:45	11 a.m.	12 noon	3 p.m.
1	0	4,1	4,1	1,7	2,3	
2	3	4,1	9,1	3,3	2,3	
3	5	4,2	21,9	4,5	2,1	
4	10	5,1	25,7	9,7	4,7	
5	10	3,8	30,3	19,8	9,8	
6	0	4,0	4,0	2,6	3,2	

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From the table it can be seen that moisture in the soil surface in plots No. 2-5 immediately after watering increased sharply, but in only one hour in plots No. 2 and 3 the moisture in the surface had dropped sharply and approached the natural moisture in plots No. 1 and 6. In plots No. 4 and 5, where watering corresponded to 10 mm, the moisture remained markedly high. Four hours after watering the moisture in all plots with a mechanically treated surface (No. 2-4) were practically equal to the natural level. In plot No. 5 with an undisturbed surface a significant reduction was also observed in moisture, but it still slightly exceeded the natural level.

Results of spectrometry conducted before watering showed that spectral curves of brightness of mechanically treated plots (No. 1-4) show practically no difference. Spectral curves obtained from plots No. 5 and 6, remaining in a natural state, also do not differ from each other, but have higher values (Fig. 2), indicating the significant effect of the structure of the soil surface on reflective capacity.

Analysis of spectral curves obtained immediately after watering (Fig. 3) showed that with increase of moisture, SBR of the soil are reduced in accordance with the degree of its moistening. The sharpest reduction of SBR (50-60%) is observed in plot No. 4 with a moisture content of 25.7%. In plot No. 3, with moisture of 21.9%, spectral brightness was reduced approximately 40%, and in plot No. 2, with moisture of 9.1%, reduction of brightness was insignificant, indicating the closeness of the moisture content to the limit of the gradientless range (Fig. 1).

A comparison of SBR curves for plots with treated and untreated surfaces shows (Fig. 3) that SBR values for plot No. 5 (with 30% moisture) are the same as for plot No. 2 (9% moisture). Such a course of SBR curves is due to differences in the structure of the surface of the experimental plots and indicates the importance of accurate calculation of this factor in studying the effect of moisture on SBR.

In an hour after watering (Fig. 4), moisture was reduced in all experimental plots and, correspondingly, SBR values were increased. As plots No. 2 and 3 dried to their initial moisture content, brightness became even slightly higher than the original level. This increase of SBR is due to change in the structure of the soil surface because of watering, which smooths the surface and reduces its roughness.

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In four hours after watering, in all experimental plots with mechanically treated surfaces, the moisture of the soil surface becomes approximately equal to that in the plot left under natural conditions and no longer has an effect on SBR.

Our studies are the first experimental test in our cycle of works to evaluate the effect of different natural factors on SBR and the photo image. Our experiment shows that the structure of the soil surface has an important effect on SBR; as the result of rapid drying of the surface, in only several hours after watering soil moisture has no effect on brightness ratios in the visible band of the spectrum.

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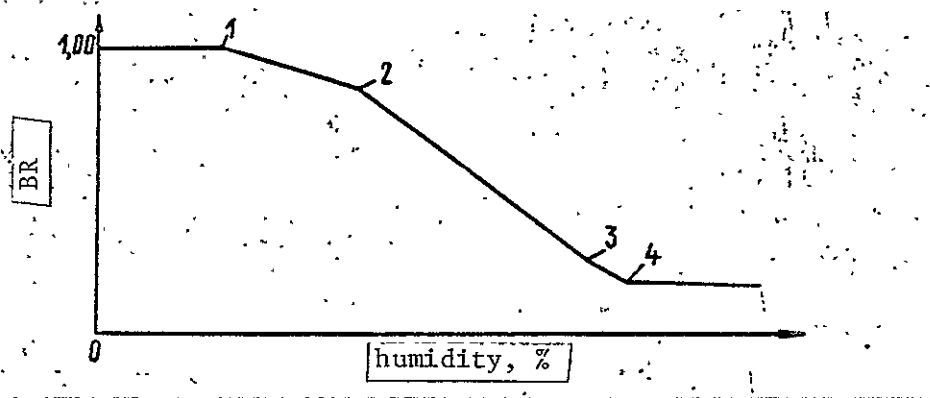


Figure 1. Generalized course of brightness ratio, expressed in relative units, depending on soil moisture. Figures on graph indicate moisture in soils: 1 - air-dry soils; 2 - maximum hygroscopicity of soils; 3 - least moisture capacity of soils; 4 - complete moisture capacity of soils.

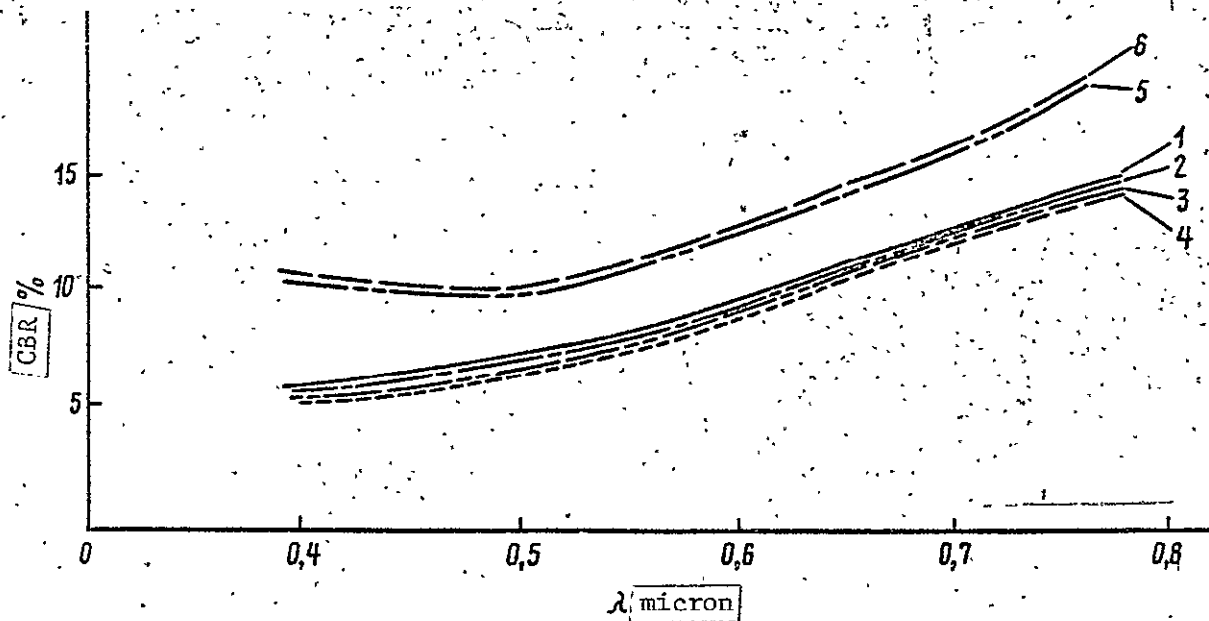


Figure 2. Course of spectral brightness ratio of soil with natural moisture: with mechanically treated surface

plot No. 1 with 4.1% moisture

plot No. 2 with 4.1% moisture

plot No. 3 with 4.2% moisture

plot No. 4 with 5.1% moisture

with mechanically untreated surface

plot No. 5 with 3.8% moisture

plot No. 6 with 4.0% moisture

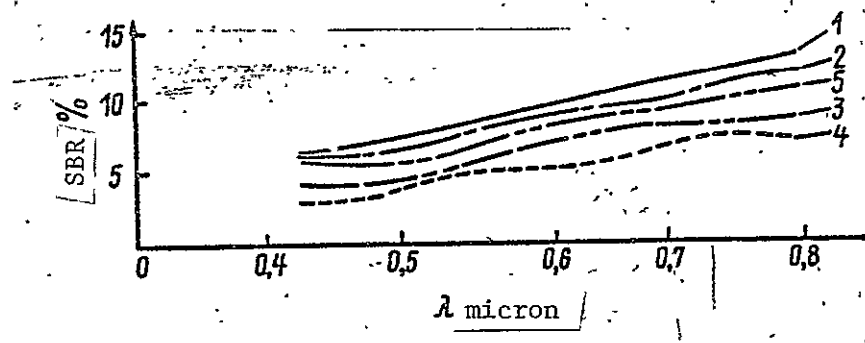


Figure 3. Course of spectral brightness ratio of soil after artificial moistening:

- plot No. 1 with 4.2% moisture
- plot No. 2 with 3.1% moisture
- plot No. 3 with 21.9% moisture
- plot No. 4 with 25.7% moisture
- plot No. 5 with 30.3% moisture

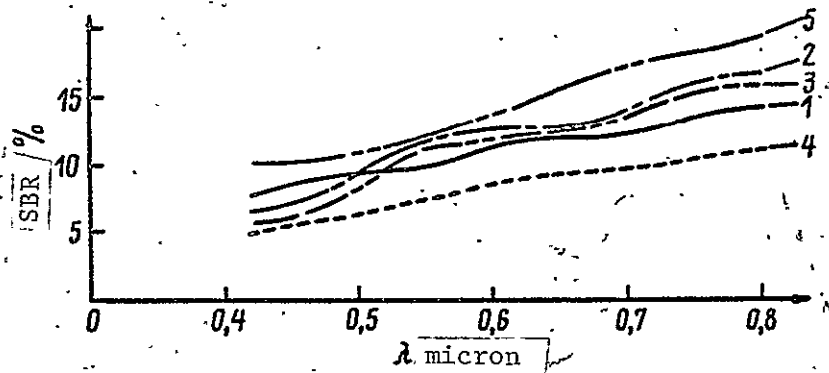


Figure 4. Course of spectral brightness ratio an hour after watering:

- plot No. 1 with 1.7% moisture
- plot No. 2 with 3.3% moisture
- plot No. 3 with 4.5% moisture
- plot No. 4 with 9.7% moisture
- plot No. 5 with 19.8% moisture

SOME CRITERIA FOR EVALUATING THE INFORMATIONAL VALUE  
OF MULTIBAND PHOTOGRAPHS

L. A. Vedeshin, I. S. Garelik and D. G. Tsvetkov

Multiband photography — simultaneous photography in several more or less narrow bands of the electromagnetic spectrum — is a promising method for remote study of natural resources. Actually in multiband photography reflected energy and intrinsic radiation are recorded in narrow spectral bands. This makes it possible then to synthesize remote sensing data in any of numerous combinations, either as color images or in digital form. Color synthesized images (in false or natural colors) exceed the quality of visual identification and digital synthesis is used for automatic identification based on the theory of pattern recognition. Recently intensive studies have been conducted in the area of creating multiband surveying systems and using multiband survey data to solve various problems in studying the natural resources of the Earth. Of paramount importance in this is selection of optimum parameters for the equipment and survey conditions to obtain the most complete qualitative-quantitative information on test objects. In particular, one of the most important is the problem of selecting the most informative spectral bands and groups of bands.

The great variety of problems involved in studies of the natural environment and in natural objects themselves complicates solution of this question. It is theoretically clear that from the point of view of informational value, for each problem of Earth resources research (ERR), there should be a best set of spectral bands. But at the same time it is evident that it is not technically possible or economically feasible to conduct surveys in a given set of bands only to solve one particular problem. Attempts are usually made to eliminate this contradiction by selecting a combination of spectral bands which would be optimum for simultaneous solution of the largest number of all posed ERR problems most important at the time. However, a set of 3 or 4 fixed narrow (Kondrat'yev, et al., 1973) or wider bands (multispectral scanner ERTS-A) can hardly be considered universal and completely satisfactory for solving the numerous and varied ERR problems. It would probably

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be more correct to determine several such sets of spectral bands, each of which would be best for a number of comparatively similar ERR problems. It is assumed that satisfactory solution of the question must entail several steps. First, the most informative bands and sets of bands are determined for individual specific ERR problems. When such sets are established, we can go on to the next step — determination of optimum sets of bands for solving more or less broad groups of similar problems. In the next step several optimum sets can be determined for operational systems to study natural resources. Such an approach to the problem of selecting spectral bands is based on preliminary classification of specific practical problems.

In many works the problem of selecting informative spectral bands is solved in connection with the problem of separating basic classes and types of natural objects according to the classification of Ye. L. Krinov. However, as already correctly indicated (Khodarev, et al., 1974), the majority of practical problems (and the main difficulties) relate to recognition of natural objects within classes and types. Therefore, it is logical to begin evaluation of the informational quality of bands for recognizing such objects.

There is a variety of approaches to solving the problem of selecting informative spectral bands using different initial data and criteria. This problem has been solved by analyzing spectral contrasts (Ivanyan, 1972) and by analyzing curves of entropy, calculated according to spectral brightness ratios (Kondrat'yev, et al., 1972). Selection of informative bands for solving automatic identification and mapping problems was made experimentally by evaluating the accuracy of machine recognition of various objects (rocks, soils, vegetation) using different combinations of bands (Smedes, et al., 1970). We shall discuss several possible methods of evaluating the informational quality of spectral bands according to multiband survey data. The use of multiband surveying as initial data for selecting informative spectral intervals has a number of advantages in comparison with the curves of spectral brightness ratios used in a number of works. First of all, an extensive airplane experiment (Khodarev, et al., 1974) will produce a large number of multiband photos taken in different landscape zones and under various photography conditions. This will offer the opportunity of evaluating the informational quality of spectral intervals for solving a number of varied problems in the investigation of different natural objects.

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Second, multiband photographs help determine not only average statistical characteristics, but also dispersions, making it possible to carry out mathematically stricter analysis of the informational quality of spectral bands.

Let there be multiband survey data (for example, photographs in several bands) of some local area. In this section there is a set of classes of objects ( $V$ ). The purpose of identification is to recognize classes within this set. But for reliable solution of this problem, first it is necessary to determine what photographs of the existing multiband collection are the best, the most informative. In this situation the problem of determining the most informative photographs (bands) corresponds perfectly to the problem of determining the usefulness of signs in pattern recognition. Let us consider possible solutions in a specific example.

There are photographs of a local area obtained in 5 bands. The problem of recognition consists of using the measured optic density of picture elements\* ( $D_i$ ) to determine to which of six classes of objects ( $V_i$ ) the given element belongs. Classes selected were: forest (1), plowed field (2), mowed steppe (3), unmowed steppe (4), pastured steppe (5), gully (6)(Fig. 1). For simplicity, in this case we are using a limited number of classes and it is assumed, as already indicated above, that we can in some way distinguish objects in this set of classes from others in the photograph. In theory the problem can be solved for all classes of objects in the photograph.

In order to compare signs, it is necessary to describe classes in the language of these signs. In the case of probability signs, which are optic densities of images, it is necessary to determine the law and parameters of probability distribution of optic densities of picture elements for each class in each band. This problem is solved by means of photometry of the negatives and subsequent mathematical analysis of the results. The work consists of the following operations:

- 1) photometry of negatives and sensitometric wedges (on G-11 microphotometer with G 11 B1 recorder), 2) plotting characteristic curves and determining contrast coefficients of negatives (according to measurement data of wedges), 3) measurement of registrograms and comparison of variation series of optic densities for all

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\*By picture element is meant a section with area on the same order as the diaphragm of the measuring instrument.

studied classes of objects in all bands, 4) calculation of probability characteristics of optic density distribution: mathematical expectation  $M(D)$ , dispersion  $G^2(D)$  and standard  $G(D)$ . To ensure comparability of results, corrections are introduced into calculated values of probability characteristics to reduce negative contrasts to the same coefficient ( $\gamma = 1$ ) and compensate the effect of uneven illumination in the focal plane due to optics of the objective and the operation of the shutter. Calculated values of  $M(D)$  and  $G^2(D)$  for a given case are given in Tables 1 and 2. Table 1 contains calculations of mathematical expectation ( $M(D)$ ) and dispersion ( $G^2(D)$ ) without taking the above indicated corrections into consideration and Table 2 - takes them into account.

Table 1

bands	I		II		III		IV		V	
	$\mu$	$\mu$	$\mu$	$\mu$	$\mu$	$\mu$	$\mu$	$\mu$	$\mu$	$\mu$
objects	$M(D)$	$G^2(D)$	$M(D)$	$G^2(D)$	$M(D)$	$G^2(D)$	$M(D)$	$G^2(D)$	$M(D)$	$G^2(D)$
1	0,78	0,0007	0,64	0,0009	0,68	0,0017	0,68	0,0016	0,74	0,0013
2	0,84	0,0002	0,72	0,0003	0,77	0,0002	0,79	0,0002	0,85	0,0003
3	0,78	0,0002	0,70	0,0004	0,74	0,0002	0,66	0,0004	0,76	0,0002
4	0,82	0,0001	0,75	0,0004	0,80	0,0002	0,78	0,0004	0,84	0,0006
5	0,82	0,0006	0,74	0,0001	0,80	0,0006	0,69	0,0004	0,80	0,0005
6	0,80	0,0005	0,73	0,0001	0,80	0,0004	0,66	0,0009	0,73	0,0004

Table 2

bands	I		II		III		IV		V	
	$M(D)$	$G^2(D)$	$M(D)$	$G^2(D)$	$M(D)$	$G^2(D)$	$M(D)$	$G^2(D)$	$M(D)$	$G^2(D)$
objects	$M(D)$	$G^2(D)$	$M(D)$	$G^2(D)$	$M(D)$	$G^2(D)$	$M(D)$	$G^2(D)$	$M(D)$	$G^2(D)$
1	2,11	0,0029	1,51	0,0012	1,79	0,0045	1,56	0,0041	1,45	0,0010
2	2,16	0,0008	1,52	0,0008	1,95	0,0015	1,67	0,0003	1,49	0,0003
3	1,99	0,0024	1,47	0,0009	1,85	0,0035	1,45	0,0016	1,39	0,0004
4	2,04	0,0008	1,53	0,0004	1,96	0,0015	1,63	0,0036	1,45	0,0010
5	2,05	0,0033	1,52	0,0003	1,96	0,0034	1,50	0,0008	1,42	0,0002
6	2,09	0,0024	1,60	0,0003	2,04	0,0023	1,51	0,0025	1,41	0,0003

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Having these data, we can proceed to comparing the informational quality of photos in different bands from the point of view of the most reliable recognition of the indicated six classes. In the theory of pattern recognition there are several criteria of sign usefulness. Here two of them are considered, the most suitable for our case:

Quite complete and strict evaluation of sign usefulness is based on calculation of the amount of entropy and information.

According to the Bayes formula, a posteriori probability of a picture element ( $D_{iil}$ ) belonging to an object of class  $V_i$  is:

$$P(V_i/D_{iil}) = \frac{P(V_i)P(D_{iil}/V_i)}{\sum_{i=1}^m P(V_i)P(D_{iil}/V_i)} \quad (1)$$

Here  $P(V_i)$  — a priori probability of class  $V_i$ , and  $P(D_{iil}/V_i)$  — probability of optic density of the picture element falling in interval ( $D_{iil}$ ) on the condition this image is an object of class  $V_i$ .

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Indeterminacy of solution of the problem of recognition, under the condition that the input of the system includes image  $D_{iil}$ , is equal to conditional entropy ( $H(V/D_{iil})$ ).

$$H(V/D_{iil}) = - \sum_{i=1}^m P(V_i/D_{iil}) \log P(V_i/D_{iil}). \quad (2)$$

The value of entropy will differ for different images. Sign usefulness is characterized by complete entropy, averaged for all images, taking into account probabilities of the appearance of these images:

$$H_k(V/D) = \sum_{iil=1}^n P(D_{iil}) H(V/D_{iil}). \quad (3)$$

Here  $k$  — number of signs, i.e. in our case the number of bands,

$n$  — number of intervals into which the range of optic densities is divided,

$P(D_{iil})$  — probability of the appearance of the image in the density interval  $D_{iil}$ :

$$P(D_{iil}) = \sum_{i=1}^m P(V_i)P(D_{iil}/V_i). \quad (4)$$

Our specific calculations were carried out with two assumptions. The first concerns a priori probabilities of the appearance of objects. The value of  $P(V_i)$  can be calculated as the ratio (typical of a given landscape) of area occupied by object  $V_i$  to the sum of areas occupied by all objects of set  $V$ . Such data can be obtained, for example, from literature sources or maps. As this work pursued only methodological purposes, for simplicity, a priori probabilities of the appearance of all objects were taken as equal to each other, i.e.  $P(V_i) = \frac{1}{6}$ . The second assumption concerns establishment of the law of the probability distribution of optic densities of photographed objects. Theoretically, in the calculation of entropy, instead of theoretic probabilities of falling into given intervals, experimental values of corresponding frequencies could be used. However, such an approach has a number of drawbacks: there is a sharp increase in the amount of initial data and it is more difficult to unify calculations and use computers to solve large volume-problems. In many works researchers, for example (Yantush, 1970; Fu, et al., 1969), have noted that the probability distribution of optic densities of images of many natural objects is close to normal. Therefore, all our calculations were made assuming normal distribution. An example of calculations according to the above formulae is given in the table (see Appendix).

Column 1 gives optic densities of interval boundaries ( $D_{iil}$ ). The entire range of optic densities is divided into intervals 0.02 D wide. Columns 2 give standardized interval limits, i.e.  $\frac{D_i - M(D_i)}{G_i}$ . Columns 3 give summary values of La Place functions according to arguments from columns 2. Columns 4 - probabilities of falling into the given interval, obtained as the difference of La Place functions for two adjacent interval boundaries. Columns 5 - a posteriori probabilities of those picture elements whose optic density falls in the given interval belonging to the corresponding class of objects. A posteriori probabilities are calculated according to formula (1), which in tabular symbols is written:

$$(5_i) = \frac{P_i(4_i)}{\sum_{i=1}^m P_i(4_i)}$$

Here  $(5_i)$  and  $(4_i)$  are numbers taken from column 5 and 4 for  $i$ -object. Columns 6 give products of  $P(V_i/D_{iil}) \log p(V_i/D_{iil})$ , obtained from the table (Barabash, et al., 1967) according to arguments of column 5. Values in column 7 are obtained according to formula (4); they are sums by lines of the products of values from columns 4 and a priori probabilities of objects  $P(V_i)$ . In column 8 are given values of entropy by intervals, i.e. sums from columns 6 by lines (formula 2). And, finally, the average value of entropy is calculated according to formula (3) as the sum of products of numbers in the same line in columns 7 and 8.

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The method of calculating entropy gives sufficiently accurate and complete quantitative characteristics of the informational value and, what is very important — in theory makes it possible to compare not only individual signs, but also their groups, i.e. it makes it possible to select the most informative combinations of bands. In particular, the statistical relation between spectral bands is studied in advance and only the statistically independent are used; then the rule of selecting the most informative combination of bands in certain amount consists of selecting bands in the order of increasing values of average entropy (Barabash, et al., 1967). However, a serious disadvantage of the method is the large volume of calculations, especially in analyzing the informational quality of groups of statistically dependent signs. It is quite simple to determine informational value by comparing probability characteristics of signs of objects (Gorelik, Skripkin, 1974). Besides simplicity and a small volume of calculations, an advantage of this method is that there is no need to know laws of probability distribution of signs of objects. This method is based on the following. It is clear that the best separative property will belong to that sign whose values (other conditions being equal) change sharply in transfer from one object to another. Mathematically the best sign must have large dispersion of mathematical expectations of optic densities (in our case) of all classes of objects. For example, band I will be more informative than band II if:

$$\sigma^2[M_{Ii}(D)] > \sigma^2[M_{IIi}(D)].$$

On the other hand, better separative property will be shown by the sign whose values (other conditions being equal) change less within limits of one object. In other words, in the best sign the mathematical expectation of dispersions of optic density of all classes of objects must be least.\* For example, band I will be more informative than band II if  $M[\sigma^2_{Ii}(D)] < M[\sigma^2_{IIi}(D)]$ .

As both factors (change in values of sign, a: within limits of one class and b: in transfer from one class to another) act simultaneously, the general result of their action will depend on the ratio of these factors. Therefore, as the ultimate criterion of informational quality K we take ratio

$$K = \frac{M(\sigma_i^2)}{\sigma^2(M_i)} \quad (5) \quad /206$$

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\*We must stipulate that this is true if we are speaking of recognition of objects by measured optic densities of their picture elements, i.e. instrumental identification. If we mean visual recognition, then evaluation of the informational value of this criterion can be directly opposite. In fact, great dispersion of optic density can reflect the typical texture of the image, which itself is a highly informative sign in visual identification.

Results of the calculation of criteria for informational quality by both methods are given in Table 3. Criteria  $H_1$  and  $K_1$  are calculated according to data in Table 1, criteria  $H_2$  and  $K_2$  by data in Table 2. Figures in the last column of the table show what place the corresponding band occupies in visual evaluation of informational quality.

Table 3

criteria bands	$H_1$				$H_2$				
	$M_1(\sigma^2_i)$	$\sigma_1^2(M_i)$	$K_1 = \frac{M(\sigma^2_i)}{\sigma^2(M_i)}$	$M_2(\sigma^2_i)$	$\sigma_2^2(M_i)$	$K_2 = \frac{M(\sigma^2_i)}{\sigma^2(M_i)}$			
(0,45-0,55)	1,82	0,0004	0,0005	0,80	1,87	0,0021	0,0030	0,70	5
(0,48-0,59)	1,58	0,0004	0,0013	0,31	1,75	0,0007	0,0015	0,47	4
(0,54-0,65)	1,53	0,0006	0,0019	0,31	1,74	0,0033	0,0067	0,49	3
(0,58-0,69)	1,45	0,0006	0,0029	0,21	1,59	0,0022	0,0058	0,38	1
(0,68-0,76)	1,47	0,0006	0,0022	0,27	1,72	0,0005	0,0011	0,45	2

Analysis of Table 3 leads to certain conclusions. First of all, let us note the agreement of results obtained by the two methods — by calculation of entropy and by comparing probability characteristics. However, we must note that the reliability of evaluation by criterion H is higher than by criterion K, as the accuracy of calculating criterion K depends not only on errors of measurement of optic densities (this source of errors also affects the accuracy of determining H), but also in large measure on values of characteristics  $M(\sigma^2_i)$  and  $\sigma^2(M_i)$ . With low values of these characteristics, large relative errors in determining criterion K can lead to an erroneous conclusion on the informative value of bands.

Agreement between quantitative evaluation of the comparative informative value and visual evaluation can be considered a certain verification of the correctness of evaluation by criteria H and K. However, there is no basis for considering such agreement mandatory. What is more, it can be expected that in a number of cases these evaluations can be directly contradictory. The question of possible reasons for this and of the mechanism and psychophysiological criteria of visual evaluation of informational quality by itself is of great interest and requires special study.

The distribution of bands by informative degree was in this case the same both by criteria taking into account corrections for reducing contrast to one coefficient and for uneven illumination in the focal plan and by criteria calculated without taking these corrections into account. Without making hasty conclusions on the basis of analyzing a limited amount of material, we can note only that distortion

of optic densities, for the above indicated reasons, evidently, has no significant effect on evaluation of informational quality. In our case this can be in part due to the fact that contrast coefficients of different films and the laws of distribution of illumination in focal planes of different cameras are accordingly similar.

A direct result of analysis of Table 3 is the conclusion that for recognition of basic natural conditions of the typical landscape of the chernozem zone, the most informative spectral interval of those considered is 0.58-0.69 micron, and the least informative - 0.45-0.55 micron. Quantitative criteria for evaluating informational quality can be used to select the best conditions for surveying and for photographic analysis of negatives. For example, we can define entropy as a function of the coefficient of contrast  $\gamma$  and we can search for the best coefficient of contrast under the condition  $H(\gamma) = \min$ .

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As already indicated above, as a result of the airplane experiment we can expect a large amount of multiband survey data. In connection with this, the above listed methods of determining the informational value of spectral bands by multiband photos can be useful.

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band	1	2	3	Appendix
statistical characteristics	$M(D) = 1.51 \quad \sigma = 0.035 \quad P = 1/6$ $M(D) = 1.52 \quad \sigma = 0.28 \quad P = 1/6$ $M(D) = 1.47 \quad \sigma = 0.03 \quad P = 1/6$			
optic characteristics				

1	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
1.38	3.71	0.500									3.00	0.499			
1.40	3.14	0.499	0.001	0.100	0.332						2.33	0.490	0.009	0.900	0.137
1.42	2.57	0.495	0.004	0.098	0.328	3.57	0.500				1.67	0.453	0.037	0.902	0.134
1.44	2.00	0.477	0.018	0.136	0.392	2.86	0.498	0.002	0.015	0.091	1.00	0.341	0.112	0.848	0.202
1.46	1.43	0.424	0.053	0.189	0.454	2.14	0.484	0.014	0.050	0.216	0.33	0.129	0.212	0.757	0.304
1.48	0.86	0.305	0.119	0.254	0.502	1.43	0.424	0.060	0.128	0.380	0.00		0.258	0.551	0.474
1.50	0.29	0.114	0.191	0.235	0.491	0.71	0.261	0.163	0.201	0.465			0.212	0.261	0.506
	0.00		0.228	0.202	0.466	0.00	0.000	0.261	0.231	0.488			0.112	0.099	0.330
			0.191	0.152	0.413			0.261	0.208	0.471			0.037	0.030	0.152
1.54			0.119	0.213	0.475			0.163	0.292	0.519			0.009	0.016	0.096
1.56			0.053	0.144	0.403			0.060	0.163	0.427			0.001	0.003	0.025
1.58															
1.60			0.018	0.041	0.189			0.014	0.032	0.159					
1.62			0.004	0.010	0.066			0.002	0.005	0.038					
1.64			0.001	0.009	0.061										
1.68															

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4						5					6						
M(D) = 1.53 σ = 0.002 P = 1/6						M(D) = 1.52σ = 0.017 P = 1/6					M(D) = 1.60 σ = 0.017 P = 1/6						
2	3	4	5	6		2	3	4	5	6	2	3	4	5	6	7	8
																0.002	0.469
																0.007	0.462
4.00	0.500															0.022	0.685
		0.001	0.004	0.032												0.047	1.006
3.00	0.499				3.53	0.500											
		0.022	0.047	0.207					0.009	0.019	0.109					0.078	1.672
2.00	0.477				2.35	0.491											
		0.136	0.167	0.431					0.110	0.135	0.390					0.135	2.283
1.00	0.341				1.18	0.381											
		0.149	0.132	0.386					0.381	0.337	0.529					0.189	2.199
0.50																	
0.00	0.192				0.00	0.000											
		0.384	0.306	0.523					0.381	0.304	0.522					0.209	2.081
										3.53	0.500						
		0.149	0.267	0.509					0.110	0.197	0.462			0.009	0.016	0.096	0.093
										2.35	0.491						2.157
		0.136	0.369	0.531					0.009	0.024	0.129			0.110	0.298	0.521	0.062
										1.18	0.381						2.036
		0.022	0.051	0.219							0.381			0.381	0.875	0.169	0.073
										0.00	0.000						0.736
		0.001	0.003	0.025										0.381	0.982	0.026	0.065
														0.110	0.991	0.013	0.018
														0.009	1.000	0	0.002
																	0.000

H<sub>ar</sub> = 1.75



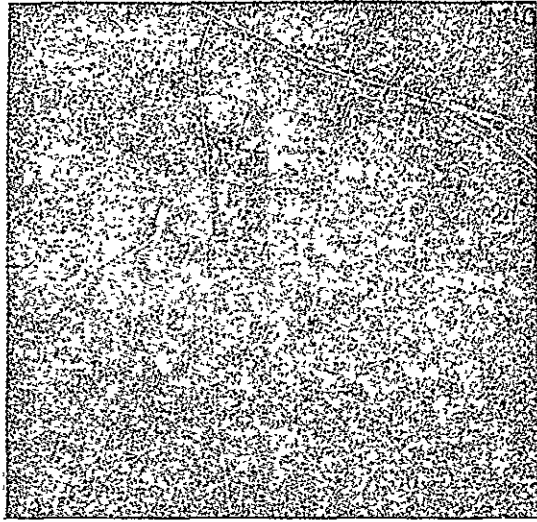


Figure 1. Aerial photograph obtained in 0.58-0.69 micron band

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WATER PROBLEMS AND PROSPECTS FOR THEIR SOLUTION  
USING AERIAL SURVEY DATA

G. L. Kalinin

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Prospects for the development of hydrology in connection with man's entry into extraterrestrial space are determined by the level of development of this science, its ability to pose and solve new problems and most effectively use current and foreseeable possibilities of a new system of studying nature. At the present time the most important problem of hydrology is development of new remote methods for studying the dynamics of surface, soil and underground water in various phase states.

A number of branches of hydrological science are interested in the development of remote methods of study. In particular, these include:

- 1) calculation and prediction of the formation of run-off;
- 2) pollution of water supplies;
- 3) thermics of reservoirs and the ice cover;
- 4) dynamics of the snow cover and glaciers;
- 5) moisture reserves of the atmosphere and soil;
- 6) levels of underground water, exit of underground water into lakes, seas and oceans;
- 7) erosion of the soil and shores, structure of modern and ancient river networks, etc.

At the present time there are possibilities for creating new, more accurate systems of predicting hydrological processes, based both on the logic of development of hydrology and on new methods of obtaining information.

The basic positions of this work can be reduced to the following:

1. Although the objects of study of land hydrology are processes of the formation of water on the Earth's surface, the main source of information has been

only point observations of hydrometeorological stations, which because of limited coverage of the territory cannot give a complete picture of the dynamics of these processes. Indirect observations of the dynamics of hydrological processes in the territory in various scales can significantly improve study of these processes and the accuracy of their calculations.

2. The generally accepted theory of the formation of run-off in combination with certain empirical data makes it possible to use observations to obtain conversion functions from point hydrometeorological observations to run-off. The so-called genetic formula of run-off has such a general character that in theory (with certain modifications) it can also be used for new information obtained from photographs. This permits wide use of already known equipment to solve a broad range of hydrological problems with the inclusion of qualitatively new information.

3. The connection of areas of inundation (basin surface, ravine-gully and river networks) and the extent of the network of temporary water courses with hydraulic characteristics of these elements of the landscape, as well as their run-off, is close to functional. Although the structure of these connections is still not completely known, by using extensive experience of solving inverse problems, it can theoretically be established on the basis of analysis of observation data.

4. The varying sizes of the mentioned characteristics of water-catchment area filling, as well as ravine-gully and river networks, make it possible to use certain initial material of observations in calculations, depending on the resolving power of the camera. This gives great flexibility to the possibilities of using photos under the condition that a system of making predictions and calculations will be created, using as much as necessary some or other various-scale images of the Earth's surface.

5. Run-off from the surface of a basin (in the final analysis) is the difference between precipitation and run-off losses. These elements, in particular run-off losses, for a number of well-known reasons are determined extremely roughly, leading to large errors in predictions and calculations. At the same time, pictured areas of the surface of a basin covered with water can be represented as the result of transformation of the indicated differences between precipitation and run-off. This creates prerequisites for avoiding such crude characteristics in predictions and calculations and using as initial data more direct run-off factors. In par-

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ticular, we must point out such a unique characteristic as the flooded area of the basin surface, being simultaneously an index of the nourishment of surface and underground water.

6. The above creates a theoretical possibility for reorganizing the current system of predictions and calculations to another logically related system, but using new information.

7. The great importance of the new possibilities of prediction will stimulate the development of new experimental studies of the surface of basins, the structure of the water-conducting network and the complex of hydrological processes in their origins. Called on to play the basic role here are experimental test grounds, which must also specify ground observations; observations from stationary towers (photographs, radioactivity of the Earth, etc.), observations from airplanes and satellites at various altitudes.

1. Methodological basis for the prediction of run-off in aerospace photos of flooded areas of the basin surface and river network

The easiest to determine by remote data are characteristics of processes occurring on the surface of a basin, (in particular, areas occupied by a water surface).

On the other hand, there is a close to an equivalent connection between areas of inundation and subsequent run-off through the enclosing range of a river.

Thus, the problem of predictions and calculations of run-off by remote methods consists of:

a) establishing direct dependences between areas of the discussed elements of the basin covered with water and characteristics of run-off;

b) establishing typical dimensions of areas covered by water under certain hydrological conditions;

c) determining (in accordance with the resolving power of the camera) the ac-

curacy of measurement of these areas or their integral characteristics by remote methods at the present time and in the future.

The first two problems as a whole belong to the area of hydrological research. In the latter, the role of hydrology amounts to establishing requirements for remote studies to solve hydrological problems with the necessary accuracy.

As will be shown below, the variety of processes of run-off formation and the strict sequence of its development in time create extremely favorable prerequisites for the broad use of remote methods.

In fact, in the first phase of run-off formation after the water reaches the basin surface, low-lying and poorly filtered parts of the basin are filled immediately. That is, a network of flowing and non-flowing microlakes is formed on the surface of the basin. The distribution curve of areas (F) of drained and undrained microlakes is a function, little subject to change in time, of the water reserves of a basin or slope run-off. The total area covered by water can be represented as

$$F_{tot} = f(W) \quad \text{or} \quad F_{tot} = \psi (q_{slope}).$$

Sizes and areas of individual microlakes depend on permanent physical/geographic conditions (primarily gradient) and time-variable conditions of run-off formation. The smaller the sizes of microlakes, the more of them there are. The range of fluctuations in sizes of microlakes is very great: from fractions of square meters to hundreds of square meters and even several square kilometers. With heavy flooding the sizes of microlakes increase.

Areas of coverage of the basin with microlakes, measured remotely, can characterize:

a) the total basin area of microlakes, the sizes of which exceed resolving power of the camera;

b) changes in reflective capacity due to changes in the total area of the water surface of the microlakes.

Development of a method of solving these problems requires the combination of ground and remote observations.

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One of the basic complexities of determining temporal change in areas of a basin covered with water is the brevity of the process, which is often measured in hours or days, requiring correspondingly frequent measurements.

With measurements of natural resources from satellites at a rate of about twice a month, it is not possible to trace the dynamics of the water coverage of catchment areas.

Data of these satellites can be used to estimate the dynamics of soil moisture, which changes much more slowly. Solution of many hydrological problems requires the rate of taking measurements from a satellite in individual phases of the hydrological regime be the same as from a meteorological satellite, and in some cases greater.

The second phase of run-off formation consists of the arrival of water in ravines and dry valleys.

During flood time, quite significant water courses are formed in dry valleys, as the drainage system of dry valleys usually covers 5-10 km<sup>2</sup> with very broken relief and up to 20-25 km<sup>2</sup> in poorly broken relief. The process of run-off formation here takes longer than from slopes.

We must note that transition from one phase of run-off to the next takes a short time.

The next phase is sequential formation of run-off of first, second and higher order rivers.

Depending on the resolving power of remote measurements, initial elements for which the area of the river surface is determined must be rivers of several orders and, therefore, different (in indexes and sizes) characteristics of surface run-off. The filling of the ravine-gully and river channel network is characterized by the area of channel and water meadow inundation.

It must be kept in mind that decoded space photos are already being successfully used to obtain morphometric characteristics and evaluate river conditions. Standard identification of space photos for a number of regions shows that in practice they

reflect the entire river and lake network. The broad scan of the photos makes it possible to study the structure of the network as a whole.

Even small permanent rivers (less than 10 km) are seen in these pictures, the channel is clearly reflected in all details. Temporary water courses are reliably recognized in space photos looking like light-gray elongated, sometimes winding bands. In significantly more detail than on large-scale maps, it is possible to distinguish boundaries of flood meadows along rivers, marked by a general darkened tone. Therefore (especially in the case of catastrophic flooding characterized by large overflows), the use of space and airplane surveying can help make quite highly accurate predictions.

## 2. Determination and prediction of surface run-off by the area of a basin covered with water

Between the surface influx of water into the river network ( $q$ ) and the volume of water ( $W$ ) on the surface of the basin, there is a close to functional connection:  $q = f(W)$ ; on the other hand, between the area of water coverage on the basin surface  $\omega$  and  $W$  there is also a close to functional connection:

$$W = \varphi(\omega).$$

Thence

$$q = \psi(\omega).$$

Thus, to determine the influx of surface water into a river network it is necessary to solve two problems: determine the portion of basin area covered by water and find the form of connection between this value and the influx of water into the river network.

The first part of the problem is solved by aerospace methods or direct determination of the area covered by water or by the average reflective capacity of the basin surface. The latter case involves preliminary establishment of connections between these changes and coverage of the basin area with water.

Extremely promising for future studies could be determination and prediction of surface run-off by areas of different degrees of soil moisture. At the present

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time, methods have already been developed to determine water reserves in the upper layers of the soil using gamma-surveying by airplanes.

Estimation of soil moisture can also be made by satellite images in the visible range; in studying regional moisture fields, even comparatively low spatial resolutions provided by a 1 km scanning element of television images is sufficient. It has been shown that there is an extremely close correlation between the albedo of soils with different moisture content and the density of the negative image, making it possible to determine soil moisture by the intensity of the signal of a television picture.

Encouraging for study of pluvial flooding by satellite data are examples of up-dating of precipitation contours and boundaries of soil wetness by color photographs from "Gemini-4."

New opportunities for determining quantitative characteristics of soil moisture are reflected in the use of passive radar methods in the centimeter range. According to measurements of microwave radiation in 3.4 and 8.5 cm wavelengths, there is a reduction of radio brightness temperature with increase in moisture of the ground, which is linear in character. Recently a number of works have appeared which attempt to make a quantitative determination of moisture content by solving inverse problems of finding physical parameters of the soil by its heat radiation field.

Of greatest interest for purposes of hydrological prediction could be evaluation of the distribution of water in soil by depth according to measurements of radio brightness temperatures in 0.81, 2.2, 6.0 and 21.4 cm wavelengths.

The second part of the problem can be solved in two ways and their combinations: the first of them consists of theoretical/experimental justification of forms of connection  $q = \phi(\omega)$ , the second rests on solution of an inverse problem -- by observations of  $\omega$  and  $q$  is established  $\omega(q)$ .

The second problem of calculating (predicting) run-off amounts to calculating run-off by genetic formula:

$$Q(t) = \int_0^{t-r \max} f(r) q(t-r) dr,$$

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or

$$Q = a \int_0^{t=r \max} f(r) \omega dt + b \int_0^t f(t) \omega^2 dt.$$

Usually the most common are the following formulae for calculating curves of run-in:

$$f(r) = \frac{1}{r(n-1)!} \left(\frac{1}{r}\right)^{n-1} \dots$$

$$f(r) = a_1 \sin \frac{\pi r}{r \max} + b_1 \sin \frac{2\pi r}{r \max}.$$

3. Determination and prediction of surface run-off by the extent of the channel network

Extremely interesting and theoretically important and new indexes, suitable for remote identification, could be data on the length and number of temporary water courses during the flood-formation period. Study of the dynamics of the temporary river network is an interesting independent problem.

The general extent of temporary water courses  $\Sigma l$ , formed on the surface of a basin, is a function of influx  $q$ ; this summary characteristic can also be used for predicting run-off from a basin. The primary use of this characteristic is connected with the fact that linear objects are identified more readily and accurately on photographs of any scale. At the present time, however, there are no known studies to find the structure of the connection between the influx of water and the length of the temporary river network.

But we ultimately get as input function  $\Sigma l(t)$ , and as output function of the run-off in the enclosing range  $Q(t)$ .

Such a problem as predicting run-off is reduced to determination of:

$$Q(t) = \int_0^t \varphi(\Sigma l)(t-r) f(r) dr.$$

The use of changes not only in temporary water courses, but also in the picture of the river network (its extent) to evaluate discharge is extremely promising, for as water-carrying capacity increases, the extent of pictured sections of the river network (other conditions being equal) should also increase significantly. Therefore, indication properties of the river network can be useful for estimating water content. In particular, we must note that even after the passage of floods, maximum overflows and corresponding run-off can be established by the darkening of river valleys.

4. Initial data for practical use of suggested methods  
of prediction and calculation

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Initial data can be divided into three groups: ground, airplane and space.

Ground data includes observation of run-off in enclosed ranges, water levels, topographical data characterizing areas of water surface in channels and on the basin surface, as well as local relief, soil, vegetation cover, curves of the connection between channel areas and levels, soil moisture, etc. Some of these characteristics can be obtained from low-flying airplanes and also photographs from observation towers.

These data can be used for several purposes, namely:

1) development of a method of prediction and calculation in certain basins and run-off stations and establishment of the effect of the accuracy of measured elements on prediction error.

2) finding dependences necessary in using remote measurements, for example, establishment of the kind of connection between the area of large accumulations of water on the basin surface and the total area of water coverage in the basin under various physico-geographic conditions.

3) determination of the effect of physico-geographic characteristics of basins on the connection between measured run-off factors and amounts of run-off for devising a method of conversion from studied basins to unstudied.

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4) use of these data to identify photographs from spacecraft and high-altitude airplanes.

5) compiling several kinds of predictions, especially of catastrophic floods (particularly of villages).

Resolving power of aerial cameras varies in an extremely wide range from 50 to 12,500 m. The scale of the survey ( $m$ ), as is known, is determined primarily by altitude ( $H$ ) and focal length of the survey camera  $f$ . If we do not take into account the angle of inclination of the survey or the curvature of the Earth, then  $\frac{1}{m} = \frac{f}{H}$ .

For the purposes under consideration, most important will be craft with low orbits or in part medium orbits, which can provide highly accurate observations for the above named small objects.

The resolving power of the multispectral scanning system (MSS) and the RBV television system of the ERTS-1 satellite with 6000 scanning lines approaches that obtained by manned spacecraft from lower altitudes.

One of the most complicated problems in obtaining reliable aerospace photos at any time is exclusion of the effect of clouds and vegetation. Extremely promising for excluding the effect of clouds are research studies of measurements in the radio range (centimeter). In tests in the radio range, either the Earth's surface must be radiated by radio waves from a generator mounted in the system or the intrinsic radiation of the Earth and atmosphere must be recorded (passive system). And in some cases, to exclude the effect of clouds, in particular in the case of catastrophic floods, it can be advisable to use low-flying airplanes and helicopters as well as satellites. In general, let us note the extremely great promise of using these airplanes to develop a method of predictions. We must also note that actual resolution will also depend on the brightness of landscape elements and the transmission function of the atmosphere. For distinct landscape elements, and what is especially important for hydrology, linear objects (rivers, lakes), it can be much higher.

As noted by B. V. Vinogradov and A. A. Grigor'yev, photos made by a long-focus camera in Gemini-4 (scale 1:700,000) showed in detail the entire ravine-gully net-

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work appearing on a map of the state of New Mexico (scale 1:200,000). In the Arabian Desert, the dendriform erosion network is easily distinguished on photos from this satellite by thin light threads.

Table 1 gives the range of typical values of hydrological characteristics needed in remote measurement for the use of the suggested methods of prediction in accordance with physico-geographic characteristics of the basin and the method of prediction.

Table 1

Measured characteristic	Range of typical sizes of object
Portion of basin area covered with water	1000-30,000 km <sup>2</sup>
Areas of wet soil	1000-30,000 km <sup>2</sup>
Area of individual microlakes	from several square meters to several square kilometers
Width of water surface of ravine-gully network	10-30 m
Area of water surface of river system	length 10-300 km width 50-3000 m
Length of temporary water courses	length 1-3 km

5. Study of the snow cover and predictions of spring flooding by remote methods

At the present time, along with ground observations, aerial photographs and television pictures from satellites are being effectively used to determine characteristics of the snow cover, height of the snow line in the mountains and the area of snow coverage in basins.

As regards area of snow coverage on the basin surface, these data and especially those of aerial photographs can be used to calculate a hydrograph of melted run-off. In fact,

$$Q_t = \int_0^{t-r_{max}} \eta F_{t-r} i_{t-r} \cdot P(r) dr,$$

where  $i$  is the intensity of the water yield of snow cover;  $F$  is the area of the basin covered with snow,  $P(\bar{r})$  is the curve of run-in;  $\eta$  is the coefficient of run-

off, depending on soil moisture, depth of freezing (H) and layer of melted snow ( $x_t$ ).

$$x_t = \int_0^t i dt_0$$

The coefficient of run-off ( $\eta$ ) can be determined by empirical data

$$\eta = f(x_t, W, H)$$

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The intensity of water yield, inserted into the formula, can be calculated from ground observations by the heat balance method or more approximately by air temperature.

Soil moisture  $W$  can be determined by remote measurements in the period of time preceeding establishment of the snow cover.

The depth of freezing can be obtained by agrometeorological observations. Thus, there is the possibility of making a prediction of thawing, based on a combination of remote and ground observations.

At the same time, we are not excluding the possibility of determining water reserves in the snow cover, based only on areas of snow coverage of the basin and the law of snow melt.

Extremely interesting are the possibilities of estimating snow reserves by means of evaluating natural gamma radiation. In fact, soils and rocks contain natural radioactive elements, radiating gamma-quanta (certain elements of uranium, thorium, the radioactive isotope of potassium, potassium-40). The gamma field up to an altitude of several hundred meters is due to this source of gamma radiation. Passing through the snow cover, intense gamma radiation weakens by exponential law, depending on water reserves in the snow cover.

This method of measuring water reserves in the snow cover, developed originally by Soviet scientists, has received application and some development by foreign scientists.

Based on airplane gamma-survey data from altitudes of 25-100 m, it was possible with accuracy close to that of ground data, to obtain a field characterizing the distribution of water reserves in the snow cover.

By known values of water reserves in the snow cover ( $x$ ), determined by this remote method, long-range predictions can be made of the spring thaw. In fact, the total layer of spring run-off ( $y$ ) is expressed approximately by the equations:

$$y = x - P_0 (1 - e^{-\frac{x}{P_0}})$$

or

$$y = x - P_0 \operatorname{th} \frac{x}{P_0}$$

The physical meaning of parameter  $P_0$  is that it is equal to the maximum possible basin water absorption. For regions with deeply-frozen soils, this parameter depends only on soil moisture.

Characteristics of soil moisture can be determined by satellite or airplane surveys. The calculated dependence is compiled by data of preceding observations.

As the accumulation of water on the surface of a basin and moisture of the surface layer of soil to a depth of about 30 cm can also have an effect on reduction of gamma radiation, change in the intensity of radiation can also be used to estimate moisture reserves in the surface layer of a basin, having a decisive importance in the formation of surface and ground run-off.

#### 6. Some further problems in studying processes of run-off formation by aerospace photographs

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One of the current problems of hydrology is the use of satellite information concerning the surface of the Earth for analyzing hydrological processes.

The basic directions in solving this important problem are:

a) development of a theoretical concept making it possible to analyze processes of run-off formation by new methods;

b) conduct of a complex of ground and altitude observations of run-off formation processes both for purposes of perfecting the theory and establishing the parameter of computer models.

In connection with solving a number of hydrological problems by remote methods, including fundamental problems of predicting run-off, it is necessary to improve remote sensing equipment, on the one hand, by raising its resolving power, and on the other — by using new methods of surveying in ranges different from the visible.

The inclusion of measurement of intrinsic thermal radiation in the centimeter range by passive and active radar methods for estimating water resources of hydrological objects promises important progress in hydrology due to obtaining new quantitative information.

The creation of corresponding equipment and development of methods for quantitative evaluation of the water resources of the snow cover, atmosphere, soil and closed reservoirs by radiation in the centimeter range of the spectrum is now an extremely urgent and not complicated problem, solution of which will open wide opportunities for using remote methods in hydrology.

In addition, measurement in the centimeter range, even with existing low-resolutions, can be of great help in interpreting photographs in the visible range, as additional information not subject to the effect of clouds.

Problems in studying the condition of reservoirs, evaluation of their pollution and biological productivity, as well as change in a number of hydrological processes, for example, snow melt, can be solved by multiband surveying on the basis of regularities in the spectral albedo of water and snow covers under various conditions;

c) establishment of requirements to create optimum (from an economical and hydrological point of view) system of ground and altitude observations.

It seems that the time has come to create in interesting (in a hydrological sense) test grounds used for space research special hydrological stations with a significant program of experimental research.

Ground observations, besides their special problems, can be necessary for standard identification of remote observations conducted in test grounds from satellites and airplanes.

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A number of formulated problems of hydrological prediction can be solved only by high-resolution photos, which would inevitably entail a large flow of information. Therefore, solution of these problems must be based on standard methodological developments for typical uniform underlying surfaces in selected sections with the inclusion of images of both low and high resolution. Here space surveys of low resolution should be used to detect uniform physico-geographical sections where identification signs obtained in selected standard sections will be distributed.

The optimum system of test reference sections for high-resolution aerial photography and space surveys, the same as determination of differential (for different hydrological problems) demands for resolution power of the equipment, will be determined by the result of a comprehensive subsatellite experiment.

A no less important technical problem could be development of methods for computer analysis of images and analogous methods for the purpose of recognition, discrimination, generalization and classification of hydrological objects and phenomena, so important for hydrological processes. The use of automatic image analysis methods for hydrology is especially important as of all kinds of natural resources, water resources are the most variable element.

Analysis of the effects of different factors should serve as the basis for establishing accuracy requirements for the identification of elements, accuracy in establishing transfer functions of the atmosphere and development of new methods of studying the Earth's surface in relation to the discussed problems.

In conclusion, we must point out that the variety of processes in run-off formation, the definite sequence of their development in time with various-scale phenomena, create prerequisites for the development of a system of predicting run-off, based on phenomena varying in scale in time and space, occurring on the surface of the Earth and creates favorable conditions for subsequent (as accuracy of identification develops) use of remote sensing methods to study the formation of water conditions on land and predict run-off.



POSSIBILITIES OF USING AEROSPACE PHOTOGRAPHS IN THE GEOGRAPHIC STUDY  
OF THE STRUCTURE AND DYNAMICS OF LAND USE

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A. V. Antipova

Aerospace data delivered into the hands of geographers today gives them the opportunity of putting many kinds of research on a theoretically new base. In full measure this also applies to such a direction as comprehensive geographic study of the structure and dynamics of land use.

This direction is being most successfully developed in England, the United States and Canada. In their numerous works, scientists of these countries especially emphasize that the structure of land use is one of the most important factors affecting the general condition of the environment. And, therefore, study of the structure and dynamics of land use, development of the most rational general land utilization plans and control of the practical implementation of the latter are considered by them as one of the most effective methods of controlling the environment at the regional level.\* The use of aerospace materials to study the extremely dynamic system of land use in all the above noted aspects will ensure a high quality of research, giving it the necessary spatial accuracy and comparability in time.

From the point of view of general theoretical concepts this direction can be considered as an important element in the development of 11-, geosystemic (according to the definition of Academician I. P. Gerasimov) level monitoring, providing regional control of the condition of the environment. In essence, detection and mapping of the structure of land use is the process of determining actual spatial ratios of different natural and natural-technical geosystems.

The beginnings of the geographic study of land use were laid down in England by workers under the direction of Professor D. Stamp. In the late 1940's he pub-

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\*The third factor - land use. IUCN Bull., Vol. 3, No. 2, 1972.

lished a monograph on the lands of Great Britain,\* in which he discussed the correspondence and noncorrespondence of the modern structure of land use with the natural possibilities of the latter. This work still preserves its theoretical value, although the factual material collected from prolonged ground surveys rapidly became outdated.

Significant progress in studying the structure of land use was noted in the 1950's and 1960's when aerial photography became widespread. It became possible, by means of comparative identification of data from repeated surveys, to obtain material on the dynamics of land use in an accurately defined period of time. Such a study was conducted in the Hawaiian Islands. It revealed a distinct trend in the decade 1954-1965 toward encroachment of urban zones on agricultural lands and determined general scales and regional features of this phenomenon.\*\*

Finally, a new step in studying the structure and dynamics of land use was reached, as already indicated, in the 1970's when aerospace data became widely used in geographic research. The main advantage of these data is the complexity, synchronicity and spatial continuity of the information, as well as the possibility of obtaining rapid repeat data characterizing vast areas. These qualities of information are especially important for analyzing land use.

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The first experience of interpreting space photographs for the purpose of compiling land use maps gave very interesting results. On the "Map of land use of the southwestern United States" (scale:1:1,000,000), compiled from photographs obtained from the Gemini and Apollo spacecraft,\*\*\*, it was possible to show regional traits of land use structure in close connection with its natural landscape. Despite the comparatively small scale, such a map can also be used to estimate the condition of the environment within limits of the entire region. Eleven categories of land indicated in the map legend are quite clearly divided into three large groups which are distinguished by the degree of anthropogenic alteration of natural landscapes and which can be qualified as basic types of environment - natural, cultivated and

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\*Land of Britain: its use and misuse. By D. Stamp. 2nd edition. London, 1950.

\*\*Baker, H. L., and H. W. Dill. Urbanization of agricultural land in Hawaii. Journal. Soil and Water Conserv. Vol. 24, No. 3, 1969.

\*\*\*Thrower, N. J. W. Land use in southwestern US - from Gemini and Apollo imagery, "Ann. Ass. Am. Geogr. Vol. 60, No. 1, March 1970.

urbanized.\* Analysis of areas occupied by each type of environment and their spatial ratio gives a general idea of the quality of the environment with the current structure of land use. Analyzing data from repeated surveys, interpreted by the same method, trends can be seen in qualitative changes of the environment, calculation of which is necessary in developing monitoring problems.

Multiband space surveying, providing qualitatively much more varied information than simple photography, makes it possible to create on its base very detailed land use maps. Such are the first experimental sheets of the US "Atlas of Urban and Regional Change."\*\* A large scale map (1:62,500) and detailed legend consisting of 38 categories of land reflect quite small features of land use structure within the three large types of environment which we noted above. Thus analysis of subsequent surveys will catch comparatively small changes in the land use structure which have, however, important significance in the development of specific technical measures in organizing a regional monitoring system.

The above examples quite obviously indicate the large and still not completely realized possibilities which are connected with the use of aerospace data in the area of geographical study of the structure and dynamics of land use. Geographers developing this promising direction are faced with at least two serious problems:

1. Study of the technical possibilities of multiband surveying and development of methods of its identification in relation to comprehensive studies of land use;
2. Development of a general classification of land use (geosystems) reflecting its natural and natural-technical characteristics in combinations close to those actually existing.

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\*Antipova, A. V. The place of recreational areas in the general system of land use. In the collection: Voprosy geografii (Questions of geography). Moscow, 1973

\*\*Atlas of Urban and Regional change, USGS, NASA, 1970.

PLAN  
OF GENERAL CLASSIFICATION OF LAND USE

I. Lands practically not subjected to transformation because of poor economic utilization

- a) untouched lands (mountains, salt marshes, wasteland, etc.)
- b) nature preserves (so-called recreational land)
- c) lands used in a natural state
  - 1. hunting lands
  - 2. natural pastures
  - 3. forest-management lands (timber cutting + reforestation)

II. Lands subject to significant transformation because of intense economical use

- 1. cultivated meadows and hay fields
- 2. plantations of perennial crops
- 3. plowed fields
- 4. truck farms
- 5. irrigated lands

III. Lands subject to strong transformation because of very intense economic use

- a) urban lands
  - 1. individual structures of the suburban type
  - 2. large housing complexes
  - 3. industrial structures
- b) areas with thick transportation network
- c) mine pits

On the basis of such classification, keeping in mind the purpose of monitoring, it is advisable to represent three basic types of environment, determined by the degree of transformation of the natural landscape under the effect of economic activity (see Table 1).

(A. V. Antipova)