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(Physical Basis and Technical Means  
of Aerial Methods)

PART IV  
CHAPTERS  
XIV, XV, XVI, XVII

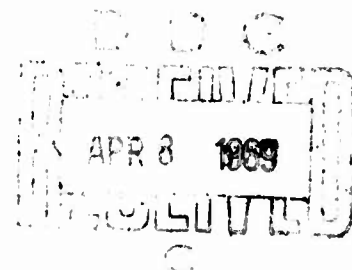
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## CHAPTER XIV

### AERIAL RADAR METHODS

Radar surveys from aircraft began to develop during World War II when a need arose for obtaining useful orientation charts under any weather conditions (darkness, cloudiness, smoke, etc., do not substantially obstruct the operation of radar).

Modern radar utilizes wavelengths from several millimeters to meters. With the aid of these waves, it is possible to obtain information on landscapes by aerial observation of the spectral reflective ability of natural and artificial objects in a given spectral band of electromagnetic vibrations.

By utilizing radar surveys, one can solve the following specific engineering and geological problems (Feder, 1960):

- 1) Obtaining information on the composition and properties of bedrock buried under thin layers of Quaternary deposits or concealed by plants or snow.
- 2) Determination of the particle size of surface sediments if the particle size is commensurate with half wavelengths of the operating radar.
- 3) Determination of soil moisture, if soil temperature is known and vice versa. /362
- 4) Determination of metal content of the earth's surface and in the subsurface layer.
- 5) Studying the properties of ice cover.
- 6) Studying the earth's surface in the dark or under a continuous thick cloud cover, etc.

These problems are solved by studying the penetration (limited to tens of centimeters and a few meters), reflection, and scattering of electromagnetic waves as determined by radar installed in aircraft. These properties depend upon the composition and certain properties of objects on the earth's surface, primarily moisture.

It is obvious that the reflection coefficient of radio waves in the radar spectrum depends substantially upon environmental conditions, which creates certain problems in the determinations of objects

by radar surveys; the radar contrast of an area, for example, changes after precipitation occurs.

A radar apparatus has recently been developed with a resolution great enough to observe the projection of landscapes on the display screen of radar tube. The picture resembles a photograph of the scene (see the attached figure).

Great attention has been given to the use of radar for a quick preparation of topographic charts (Levin, 1960; Crandall, 1963; Stilwell, 1963).

The possibilities in the use of radar surveys have already been discussed. In practice it is possible to project radar pictures whose properties enable us to plot radar charts at a scale of 1 : 250 000. The greatest significance in the use of radar surveys lies undoubtedly in the supporting and supplementary nature of radar in conjunction with other aerial methods.

## CHAPTER XV

### AERIAL METHODS UTILIZING THE INFRARED BAND OF ELECTROMAGNETIC WAVES

Infrared radiation occupies the spectral band between visible light and radio waves, i.e., between 0.7 to 300 microns. The infrared spectrum is divided into three parts: the near infrared ( $0.7 \div 1.35$  microns), medium ( $1.35 \div 5.5$  microns) and far ( $5.5 \div 1000$  microns). However, the interval of long waves utilized at the present time is about 2-14 microns. The sensitivity of modern instruments is associated with the temperature variation of most of the landscape components and the transmission of infrared radiation of atmosphere\* (Fig. XV-1 and XV-2).

Actually, the radiation of most local objects, which is caused by the reradiation of absorbed solar infrared radiation, takes place in a wider range of the spectrum with a maximum at about 9.5 microns (curve  $\delta$ ). Thus, the incident heat radiation is more favorable for the definition of local objects than the reflected heat radiation. /363

\*Fig. XV-1 and XV-2 have been taken from Fisher (1964).

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FIG. Radar Image of Ice Cover

The survey was made over a continuous cloud cover.  
1--coastal sector, disclosing the hydro-network;  
2--ice cover; 3--water.

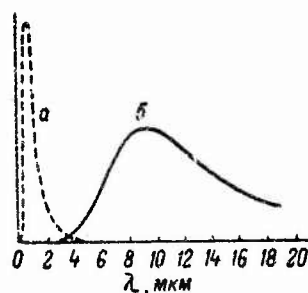


FIG. XV-1. Radiation of Absolutely Black Bodies at a Temperature of 6000°K (a) and 300°K (δ).

The earth's objects reflect the sun's heat energy in a spectrum near the curve a. Abnormally heated objects radiate their own energy in a spectrum near the curve δ. With an increase in the anomalous temperature the infrared radiation assumes shorter waves.

**KEY:** Vertical line : spectral radiation  
Horizontal line:  $\lambda$ , microns

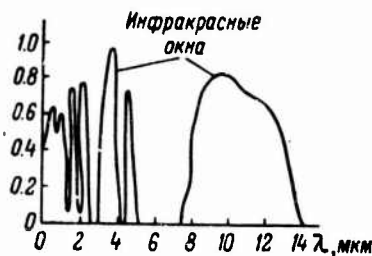


FIG. XV-2. Bands that Transmit Infrared Radiation of Atmosphere.

Between 6 and 7 microns the absorption is determined by water vapor; from 15 to 16 microns by carbon dioxide gas.

**KEY:** Vertical line : transmission coefficient  
Curve : infrared windows  
Horizontal line:  $\lambda$ , microns

It should be noted that objects on the surface of the earth radiate infrared rays that are associated with their high temperature. Such objects occur mainly in areas of volcanic activity where the temperature of normal objects may reach hundreds of degrees over a considerable area.

With an increase of temperature of these objects, the waves become shorter in the infrared radiation, transiting even into the visible band of spectrum (heated radiant lava). Therefore, when organizing infrared aerial surveys, one must select a spectral band that is more favorable for the recording of the spectral range. The band selected should, of course, be based on the anomalous temperatures that are radiated by objects (see table).

Dependence of Wavelength of the Most Intense Radiation of An Absolutely Black Body on Temperature

°C	°K	$\lambda$
0	273	10.50
10	283	10.20
15	288	10.00
20	293	9.85
25	298	9.70
30	303	9.50
50	323	8.95
100	373	7.75
200	473	6.10
500	773	3.75

Thus, for example, in order to single out objects whose temperature is several degrees above the average temperature of the earth's surface, one must measure the spectral band  $6.5 \div 14$  microns for the objects heated to the first hundreds of degrees in the spectral band  $<5.5$  microns.

In the shortwave band, up to 1.1 micron, special photographic emulsions can be used as receivers of infrared radiation. The resultant aerial photographs differ little from the aerial photographs taken in the visible spectral band (spectrozoal aerial survey; see Chapter III). The defects of this method are as follows:

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FIG. XV-3. Heat Survey of the Kilauea Volcano Area.

a--spectral range 4.5 - 5.5 microns; flight altitude 1800m.  $\int$ --spectral range 1.5-5.5 microns; elevation 5100m. In accordance with the spectral range of the survey, hotter areas of volcanic activity stand out in the upper record.



1) Low sensitivity of infrachromatic photographic materials requiring the use of intensely radiating objects and long exposures.

2) Narrow band of the long waves that are utilized.

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In the remaining part of the infrared spectrum one must use photoelectric systems that transform the invisible image into an image that is visible on luminescent screens. Such systems serve as the needed recording instruments. Photoresistances that change their conductivity when a light stream strikes them are utilized as receivers of such instruments.

Sensitivity of infrared instruments is sufficient to enable us to determine temperature differences of objects to  $0.5^\circ$ . Thus, for example, by using such instruments it is possible to detect, from a considerable height, the presence of submerged submarines by the lower temperature of deep water raised to the surface by propeller screws (Bramson and Kalikeyev, 1960).

The angular calculating ability of instruments using the infrared method does not exceed  $5 \div 6'$ , which limits the prospects of obtaining sufficiently accurate forms of investigated objects and the discrimination of details (Safronov, Andrianov, Iyevlev, 1963).

The aerial methods utilizing infrared instruments have discovered that it is possible to determine temperature of distance objects, night vision, aircraft on the ground, etc. (Ivanov, Tyapkin, 1963).

Infrared technique aids the orientation of space ships in space (vertical recorder), thermal reconnaissance and meteorological investigations (Safronov, Andrianov, Iyevlev, 1963). It is possible to obtain information on the distribution of the ice edge in Arctic seas and on the concentration of clouds in the atmosphere from artificial satellites. The latter data can be utilized for weather forecasts over the globe.

In order to study natural phenomena from aircraft by means of infrared radiation, the most promising instruments are heat finders that use a scanning beam for the observation of terrain. Encountering a number of resistances in the receiver of the heat finder, the beam emits signals which, after a corresponding amplification, are reproduced on the screen of electronic tube as a visible image--the thermal map of the terrain. With the aid of the heat finders it is possible to discriminate sections of the earth's surface which have definite temperature differences,

such as zones of volcanic activity, the outflow of subterranean water, sea currents, the distribution of permafrost as well as certain landscape components that are characterized by differing heat capacities (moist and dry soils, rocks, plants, etc). Various irrigation systems are good objects for infrared aerial surveys (Cantrell, 1964).

In forestry, the heat surveys can be utilized for precise determination of the areal limits of forest fires (Colwell, 1964). The usual aerial survey is as a rule ineffective in this case because of smoke.

Fisher (1964) investigated the Hawaiian volcanoes with the aid of aerial thermal survey. The results substantially refined the structure of volcanic zones and hydrothermal activity (Fig. XV-3). Periodic thermal surveys may indicate future eruptions in this region by detecting variations in the intensity of the thermal anomalies.

The use of the infrared scanning method for the study of zones of volcanic activity is most promising because it is here that the greatest heat contrasts in nature are observed, which sometimes last for quite a time. It is known, for example, that some Tertiary and Quaternary lavas have preserved abnormal temperatures /365 to the present time.

As was mentioned before, the temperature of the major part of natural objects is determined by solar activity and heat capacity, as well as by the effect of the surrounding medium. Therefore, at various times of the day and the year the heat contrasts of the same objects may differ or be reversed, e.g., the contrast between the river and its banks during the day and night.

Temperature, moisture, cloudiness, direction and speed of wind, and the time of survey are the main factors that affect the resultant infrared status.

The limited accuracy of heat finders, which do not record clear contours of objects, in addition to the changing contrast, is responsible for discrepancies in the determinations of objects and obstructs their identification. However, this circumstance can be utilized for the identification of landscape components when observing the same objects at various times of the day. Thus, one can study, for example, dry and moist soils, rocks, and plants.

The infrared aerial survey aimed at geological objects must be carried out during periods with maximum heat radiations from the earth's surface when the reflection is absent, i.e., when the terrestrial objects have the greatest thermal contrast. This most favorable time is just after sunset.

The aerial methods that make use of infrared techniques have just begun to develop and, therefore, they may unfold numerous unknown aspects.

## CHAPTER XVI

### AERIAL METHODS UTILIZING ULTRAVIOLET RADIATION

The ultraviolet band occupies the spectrum of magnetic oscillations that lies between the soft roentgen rays (wavelength about 1nm (normal meter)) and the visible ( $0.3 \div 0.4$  microns).

The shortwave radiation is intensely absorbed and scattered by the atmosphere, which greatly restricts its utilization in aerial surveys. In addition, the optical systems, even the quartz ones, is poorly transparent for wavelengths smaller than 120nm.

However, a number of geological formations begin to fluoresce under the influence of ultraviolet radiation. This phenomenon causes one to look for ways of utilizing the above-mentioned spectral band in aerial survey methods.

American scientists use special methods to search for petroleum in land or offshore areas by utilizing the fluorescence of carbon emitted by gas deposits when subjected to ultraviolet radiation. A special radiation source with long waves ( $0.3 \div 0.4$  microns) is used for this purpose. Electronic-optic transformers are used as receivers. Their screens are usually photographed (Madsen Andzew, 1962). It need be noted that such a reconnaissance method can record many pseudo-anomalies, such as the luminescence of the sea caused by the wakes of vessels, etc.

There have been attempts to use a combination of ultraviolet infrared reflections for the determination of large-scale diseases of plants (Colwell, 1964).

## CHAPTER XVII

## AERIAL GRAVITY RECONNAISSANCE

Aerial gravity reconnaissance is a new aerogeographical method which will undoubtedly be widely utilized in the near future.

When carrying out tests in USSR and USA with gravimeters designed for the measurement of gravity forces from vessels and submarines, a number of problems associated with specific observations from aircraft and helicopters have developed (La Coste, 1959; Nettleton, 1960; Thompson, 1960; Papov, 1963).

The problems are diverse and include normal centrifugal force, which is caused by the earth's rotation (Etwesh effect); the need for very accurate measurements of the flight altitude, in order to determine the effect of free air which is about 1mg1/3 meters; the effect of the variation of gravity due to vertical accelerations; the need for the creation of rapid calculating systems, etc. In addition, it is necessary to secure high quality positioning systems and to gather high quality information on speed and direction of the aircraft.

On the basis of tests designed for the improvement of sea gravimeter in flights at considerable altitudes (as high as 3500m), American engineers constructed charts of gravity force with accuracies as high as 10mg1 and better, i.e., the data can now be utilized for the solution of geodetic problems, as well as for deducing anomalies of the gravity force associated with large-scale structures.

When solving a number of important geological problems, such as the search for petroleum deposits, the study of crystalline beds, etc., the effect of using aerial methods would be enhanced with effective use of more promising methods of recording the gravity field. They include, for example, a method based on the polarization of ionized gas in the field of gravity force, a method of recording variations in the frequency of magnetic oscillations in the field of gravitational potential (Troshkov, 1963).

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POSSIBILITIES AND PROSPECTS OF JOINT  
UTILIZATION OF AERIAL METHODS

The existing aerial methods have different applications and reflect various characteristic properties of the objects to be investigated. Correspondingly, the application of a given method makes it possible to solve either just one specific problem or a group of problems. Thus, for example, the aerial gamma survey calls for the investigation of radio-activity of the uppermost layer of the earth's surface (to a depth of 1m) which is caused by the presence of Ra, Th and K in this layer. Magnetic anomalies depict geological bodies whose magnetic properties differ from those of the surrounding area. For the time being, aerial electric reconnaissance is investigated with artificially created electric fields that depend upon the strength of sources as well as upon the structure and depth of the bodies that conduct them. Photographically, the earth's surface is studied by utilizing the reflective ability of photographic areas in various spectral bands.

In order to gain as complete information on objects as possible, it is necessary to study them with the aid of several, not just one, complementary aerial methods by considering the properties of these objects and the objectives of the study. The combination of aerial methods is achieved by a joint utilization of data obtained during simultaneous surveys and data obtained at various dates in the same locality. In the first case, one can obtain the most dependable observation data. Surveys made from one aircraft, without additional rearrangement of instruments are, in this case, the most promising.

An example of two or more simultaneous surveys obtained by a single airplane is the work of An-2 type aircraft conducting aerial magnetic and radiometric surveys with the aid of photographic hookup. The aerial photographs were taken on various types of tapes on two different scales. Visual observations were conducted jointly with selective aerial photography and geophysical measurements.

Joint processing of data on a selected object obtained by the use of various methods from the air, as well as from the land, at various times and by various investigators, should be carried out as a preliminary step to materialize the plans drafted for a given region. E.g., the analysis of data gained by aerial photographs and data gained by various aerial geophysical surveys must be considered when planning special geological operations.

However, such a complex application of aerial survey methods is still relatively seldom practiced. More often, one of the established methods is used. When carrying out geophysical investigations, the joint use of aerial methods is usually limited to the application of complex gamma stations for a simultaneous survey of aerial magnetic and radiometric tasks. Less often is aerial photography added to probe geophysical features of the area. Only occasionally are aerial photographs used in geophysical surveys for geological interpretation of data. The reason for this, as was pointed out above, is that up to the present time all of the types of aerial survey have been developed individually, though it is known that many properties of objects to be studied are closely associated. Thus, for example, the coefficient of light refraction by a substance, which determines to a certain degree its optical properties, is related to the dielectric constant and magnetic susceptibility of the substance, etc. In a number of cases, the direct and indirect relations among physical properties have been determined empirically. E.g., a thick plant cover and special magnetic and radioactive properties of kimberlite bodies in Yakutiya single them out among surrounding rocks. There are numerous examples of plants that are associated with increased quantities of individual minerals. When searching for uranium, the gamma anomalies coinciding with magnetic anomalies are of special significance, etc.

There are numerous examples of various combined physical properties being utilized as supplementary or determining factors. Nevertheless, we are just beginning to tackle the theories that link individual properties of matter to the simplest cases of geophysical effects.

A comprehensive characterization of any given object becomes possible only when two conditions are met: first, the reciprocal relationship between the properties of individual objects and the objects themselves must be known; second, the optimal combination of various aerial methods must be worked out on the basis of the first condition.

The materialization of the two conditions requires the solution of a number of theoretical, methodical and technical problems. For this purpose, it is necessary, first, to combine and statistically process a sufficiently vast amount of data that have been gathered by various organizations for areas containing various types of geological and geographical structures.

The selection and analysis of aerial data must be done in cooperation with geologists, geophysicists, geographers, botanists, hydrologists and other experts. Special attention must be paid to the data of earth's radiation and physico-chemical analysis



of rocks, soils, and other structural elements of given regions. The established correlation between various properties of natural formations and data obtained by various aerial methods will constitute a sound basis for the selection of the most rational and economic combination of data; and--what is not less substantial--an experimental basis for the creation of a theory of complex utilization of aerial methods.

Large amounts of data are now at the disposal of geologists, geophysicists and other specialists. With rational processing, they may become valuable as direct or indirect data on which to base forecasts. Specially significant appear to be comparisons of aerial photographs with other types of aerial surveying.

Prospects of a joint utilization of various aerial methods are promising, especially if we concentrate on the prospects of using new methods, such as aerial gravimetry, photographs exposed in ultraviolet light, and the utilization of the infrared band of the spectrum.

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There is no doubt that aerial methods will aid our national economy when a complex apparatus is built, an apparatus which would automatically survey all the parameters of physical fields of the Earth in which we are interested, and which by the use of computers would process the incoming information in accordance with a program based on the theory of complex utilization of data obtained by aerial methods.

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