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JPRS L/8590

26 July 1979

USSR Report

GEOPHYSICS, ASTRONOMY AND SPACE

(FOUO 1/79)

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USSR REPORT

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I. ASTRONOMY

Translations

MASS-SPECTROMETER MEASUREMENTS OF COMPOSITION OF THE LOWER ATMOSPHERE ON VENUS

Moscow PIS'MA V ASTRONOMICHESKIY ZHURNAL in Russian Vol 5, No 5, 1979 pp 211-216

[Article by V. G. Istomin, K. V. Grechnev and V. A. Kochnev, Space Research Institute USSR Academy of Sciences, submitted for publication 26 February 1979]

Abstract: The descent modules of the "Venera-11" and "Venera-12" carried out mass-spectrometer measurements of composition of the Venusian atmosphere. It was established that nitrogen (about 4.5% by volume) is an important component of the Venusian atmosphere. Isotopes of argon (mass peaks 36, 38 and 40 a.m.u.), neon (20 a.m.u.) and krypton (84 a.m.u.) were also registered. The total content of all argon isotopes was about $150 \cdot 10^{-6}$, neon -- about $10 \cdot 10^{-6}$ and krypton -- about $0.5 \cdot 10^{-6}$. The isotopic composition of argon was very anomalous in comparison with the argon in the earth's atmosphere. The abundance of "secondary" radiogenic ^{40}Ar is equal to the total abundance of the primary isotopes ^{36}Ar and ^{38}Ar.

[Text] Mass spectrometers were included in the complex of scientific instrumentation carried by the descent modules of the "Venera-11" and "Venera-12." The purpose of the mass spectrometer measurements was a refinement of data on the chemical composition of the lower atmosphere of Venus with respect to the principal components, measurement of the content of small atmospheric impurities (especially the content of inert gases) and, finally, determination of the isotopic composition of both the principal components (carbon, oxygen, nitrogen) and inert gases.

The first communication on the results of the mass-spectrometer experiment in the dense Venusian atmosphere ("First Results...," Istomin, et al., 1979) contained data from a speedy analysis only of a part of the collected information, processed using calibrations carried out in advance. [In the future plans call for carrying out repeated calibrations in the laboratory using duplicated instruments under conditions as close as possible to real and with mixtures including a broader range of components (water, sulfur, etc.).} This communication gives the results of a more complete analysis of the collected data which is based once again only on the preflight calibrations of the apparatus. A more complete review of the material clearly confirms the data from the preliminary analysis and leaves the already mentioned concentrations of all the registered components virtually unchanged. This also applies to data on the isotopic composition, especially to data on the isotopes of argon. At the time of preparation of this communication we learned of the first results of experiments carried out on the "Pioneer-Venus" vehicles, so that here some attention will be devoted to a comparison of the results.

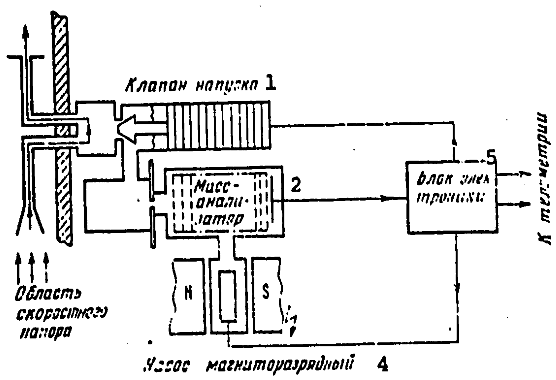

Fig. 1. Block diagram of mass-spectrometer experiment on descent modules of the "Venera-11" and "Venera-12."

KEY:

1. Admission valve
2. Mass analyzer
3. Region of velocity head
4. Magnetic discharge pump
5. Electronics unit
6. To telemetric system

The mass spectrometer used aboard the "Venera-11" and "Venera-12" vehicles was created as a result of further development of the studies carried out in this direction in the Soviet Union (Istomin, et al., 1975).

The experimental method included the use of a mass analyzer of the radio frequency type having a moderate mass resolution in combination with an impulse system for the admission of the gas sample into the mass spectrometer. Figure 1 is a block diagram of the mass spectrometer experiment. The atmospheric components, under the influence of the pressure difference arising due to the velocity head during descent of the vehicle freely passed through the cavity of the admission valve which communicated with the atmosphere by means of two open lines. During the time between successive samplings the valve cavity was repeatedly ventilated by atmospheric gases. The sampling of gas from the cavity was accomplished by brief opening of the admission valve. The strictly measured microportion of gas admitted into the mass spectrometer was evacuated from it by means of an ion-getter magnetic discharge high-vacuum pump.

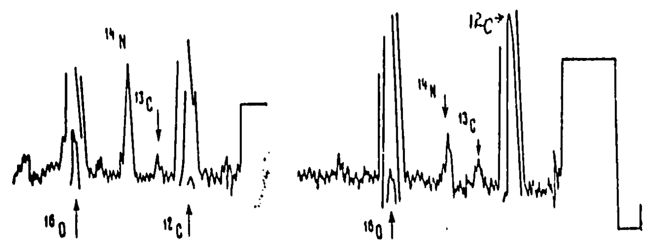

Fig. 2. Fragments of mass spectra in region 12-16 a.m.u. At left -- mass spectrum of Venusian atmosphere ("Venera-11"), at right -- mass spectrum of calibration mixture containing 1.5% nitrogen.

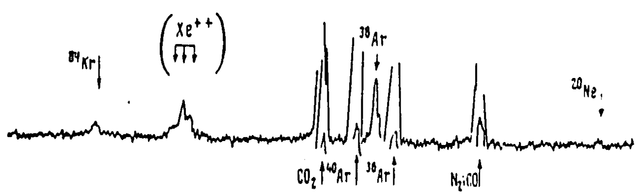

Fig. 3. Fragment of mass spectrum in region 20-105 a.m.u. obtained in a regime of analysis of inert gases with increased response ("Venera-11"). The mass peaks of neon-20 and krypton-84 are seen at the limit of response.

In the course of the experiment the mass spectrometer is automatically adjusted for admission of the required portion of gas, successively increasing the intensity of the controlling effect on the admission valve. During the entire time of search for the dose there is transmission of mass spectra. The spectrum scanning time was 1 sec. Upon attaining the required admission of gas, the instrument is switched to an analysis regime, during which eight mass spectra are transmitted for each gas portion, after which the cycle is repeated. The instrument could periodically undergo a regime of analysis of inert gases with an increased response. The response to inert gases was increased by a change in the operating regime of the magnetic discharge pump. In this process the velocity of evacuation of the inert gases was reduced to zero, whereas the rate of evacuation of chemically active gases (CO_2, nitrogen) remained virtually constant. The gain in response for the inert gases due to the shifting of the instrument into a "static" regime was ~20. All even working cycles of the mass spectrometer accomplished a regime of analysis of inert gases with an increased response.

The mass spectrometers aboard the two descent modules took the first sample at an altitude of about 23 km and operated until landing took place. The last gas samples were taken by mass spectrometers at an altitude from 3 to 1.5 km over the planetary surface. The mass spectrometers aboard the descent modules of the "Venera-11" and "Venera-12" each took 11 gas samples; a total of 176 mass spectra were transmitted to the earth. These characterized the chemical and isotopic composition of the lower atmosphere on Venus. The mass spectra were transmitted and registered in analog form. The ion current amplifier in the mass spectrometer had four response scales with amplification factors 1, 10, 10^2 and 10^3. A scale change was accomplished automatically at the mass peak, due to which the real telemetric record of the spectrum has an "illegible" form. Examples of the registered mass spectra are given in Figures 2 and 3 and are discussed below.

Each mass spectrum was preceded by the transmission of five control parameters of the mass spectrometer, which included the emission current of the ion source and the current of the magnetic discharge pump. These control parameters are shown in the spectra in Fig. 2 in the form of characteristic "steps."

Both mass spectrometers were of an identical design insofar as possible and this was true both with respect to the technology of their preparation and tests before installation on the vehicle, and in particular, with respect to their electric characteristics. In particular, great attention was devoted to the identity of the instruments with respect to the strengths of the emission currents and the ionizing potential and the retarding potential. The latter determines the mass number resolution of an analyzer of the radio frequency type. The ionizing potential was selected in such a way that in the mass spectra there were no peaks of doubly ionized CO_2 (peak 22 a.m.u.) and argon (peak 20 a.m.u.).

The principal characteristics of the mass spectrometer were as follows:

Range of mass numbers	11-105 a.m.u.
Resolution (at the level 0.1) of mass peak amplitude	$R = M/\Delta M = 35 \pm 5$
Scanning time of mass range in search regime	1 sec
Scanning time of mass range in analysis regime	7 sec
Time required for taking gas sample	less than $5 \cdot 10^{-3}$ sec
Emission current	0.4 mA
Ionizing potential	40 V
Response in % by volume (for small impurities in CO_2 in single spectrum) not less than:	
nitrogen	0.2%
neon, methane	$5 \cdot 10^{-6}$
argon, krypton	$1 \cdot 10^{-6}$
Weight	9.5 kg
Power consumption	17 va

The instruments remaining in the laboratory were also completely identical to those installed on the "Venera-11" and "Venera-12" vehicles. All instruments were used in carrying out a series of preflight calibrations, the results of which were used for a speedy analysis of the flight data. Most of the calibrations were carried out using mixtures prepared on the basis of CO_2 with a high degree of purity ($\sim$99.998%); the principal impurity within the limits of the mentioned purity was nitrogen. The content of inert gases (for the most part argon) in the initial CO_2 did not exceed $0.2 \cdot 10^{-6}$ (in volume).

The principal model mixture was a mixture containing 1.5% nitrogen, 0.4% oxygen, $175 \cdot 10^{-6}$ argon, and the remainder is CO_2 with a high purity. The mixture was prepared by means of dilution of CO_2 with atmospheric air (its composition is given as prepared). The second used mixture was a mixture with a nitrogen content $\sim$4%. The calibrations with respect to neon and krypton were carried out using air.

It appears that the principal source of systematic errors in mass spectrometer determination of composition of the Venusian atmosphere, whose results are presented below, is the error in knowledge of the composition of model mixtures. It appears that an evaluation ±10-15% is optimistic, so that the final result for the principal small components -- nitrogen and argon -- can be encumbered by systematic errors $\sim$20%.

With respect to the components which are discovered at the response limit (for a single spectrum), such as neon and krypton, the error in their determination is evaluated on a preliminary basis by a value of the order of $^{+100\%}_{-50\%}$.

These errors will possibly be reduced as a result of future work on analysis of the collected data.

Results. The principal impurity in the Venusian atmosphere, as indicated by the first mass spectra received, is nitrogen. Its volume concentration is 4.5±0.5%. This figure was obtained on the basis of measurements of the measured peak with M = 14 and is confirmed by measurements on both vehicles. The scatter of individual points in the overwhelming majority of cases falls within the mentioned error. The result for nitrogen is illustrated by the fragments of the mass spectra in Fig. 2, which compares the mass spectra for the Venusian atmosphere and the model mixture with a nitrogen content of 1.5%. It can be seen that the peak with M = 14 (nitrogen) in the spectrum of the Venusian atmosphere has a far greater value than in the spectrum of the calibration mixture (it is convenient to compare peaks with M = 14 and 13 -- the isotope ^{13}C).

The nitrogen content cited above in general is also confirmed by measurements of the peak with M = 28. This peak is the sum of the mass peaks of nitrogen N_2^+ and the CO^+ secondary peak arising as a result of the dissociative ionization by CO_2 electrons. In the case of measurements from the peak M = 28 the scatter of individual experimental points in a considerable number of cases exceeds the limits of error by 0.5%. The reasons for this are being analyzed.

The concentrations of all other impurities in the Venusian atmosphere, both chemically active gases and vapors, do not exceed several hundredths of a percent by volume.

Thus, water vapor, chlorine and sulfur are discovered mass-spectrometrically almost at the limit of response for one spectrum. Water vapor is manifested in the "excesses" of the peaks with M = 18 and 17 above the values caused by the "normal" isotopic composition of oxygen. Chlorine is discovered in in some mass spectra as a weak peak with M = 35, and sulfur -- in the form of an "excess" of the mass peak with M = 32, above the value caused by the contribution of O_2^+ ions in the ion source of the instrument due to dissociation with ionization of CO_2. Due to the fact that there were no preliminary calibrations of the mass spectra for water, chlorine, sulfur and compounds of the latter two, these data must be regarded as very preliminary. A quantitative estimate of the content of these small impurities for the time being has not been made. The excess in the mass peak with M = 32 can be attributed also to the molecular oxygen in the Venusian atmosphere. The presence of sulfur vapor in the Venusian atmosphere is far more probable than the presence of free oxygen. However, in the light of recent chromatographic measurements by Oyama (1979), according to which, in the lower atmosphere of Venus there was molecular oxygen in a concentration of about $60 \cdot 10^{-6}$, the excess in the mass peak with M = 32 which we registered can be attributed, with some difficulty, also to free O_2. In any case, some identification seems all the more necessary because optical spectrophotometric measurements made simultaneously on the "Venera-11" and "Venera-12" (Moroz, et al., 1979) reveal an exceedingly low upper limit for gaseous sulfur in the lower atmosphere of Venus.

The mass spectrometer registered a number of inert gases in the Venusian atmosphere, specifically: three isotopes of argon (36, 38 and 40 a.m.u.), neon (20 a.m.u.) and krypton (84 a.m.u.). The isotopes of argon can be seen clearly on the cited fragment of the mass spectrum in Fig. 3. It can be seen that the isotopic composition of argon is very "anomalous" in comparison with the argon in the earth's atmosphere. The abundance of "secondary" (radiogenic) isotope ^{40}Ar in the Venusian atmosphere is equal to the total abundance of the "primary" isotopes ^{36}Ar and ^{38}Ar. As is well known, in the earth's atmosphere the isotope ^{40}Ar is 300 times more abundant than the isotope ^{36}Ar. The ratio of abundances of both "primary" argon isotopes in the Venusian atmosphere, on the other hand, is the same as for argon in the earth's atmosphere.

The more precise values for the relative abundances of argon isotopes in the Venusian atmosphere are as follows (%):

$$^{36}Ar\ 42 \pm 2;\ ^{38}Ar\ 8 \pm 2;\ ^{40}Ar\ 50 \pm 2.$$

The total content of argon isotopes is estimated on a preliminary basis at $(150 \pm 50) \cdot 10^{-6}$.

The content of the neon isotope (^{20}Ne) is $(10\text{-}15) \cdot 10^{-6}$, and krypton ^{84}Kr is $(0.5\text{-}0.8) \cdot 10^{-6}$. (In the first publication ("First Results...," 1979) the krypton content was erroneously exaggerated by one order of magnitude.)

In the spectrum shown in Fig. 3, in addition to the mentioned components (argon, neon, krypton and the secondary peaks of CO and CO_2) there is a group tagged by (Xe^{++}). This is the xenon introduced into the instrument and serving as a reference for the mass scale.

Measurements of the total abundance of argon isotopes made aboard the "Venera-11" and "Venera-12" agree satisfactorily with the data published by Hoffman, et al. (1979), obtained aboard the "Pioneer-Venus" vehicle (on a large probe) and agree with the data published by Von Zahn, et al. (1979), measuring the isotopes of argon on the entry vehicle in this same experiment.

For the time being we do not understand the absence of mass spectrometer data on the nitrogen content in the lower atmosphere of Venus (Hoffman, et al., 1979). Our nitrogen data agree well with the result of the first analysis with a gas chromatograph on a large probe, the "Pioneer-Venus," although the authors themselves (Oyama, et al., 1979) consider the third chromatographic analysis to be the most reliable.

A further analysis of the collected data requires carrying out a new series of calibrations of the remaining instruments and the processing of mass spectra on an electronic computer, as a result of which there will be a decrease in the noise interference level. It can be hoped that there will be a decrease in the error in determining the absolute abundances of all the mentioned components and there will be refinement of determination of the "excesses" of the mass peaks with M = 17, 18 and 32 a.m.u., and also the isotopic composition of the principal components of the Venusian atmosphere -- carbon, oxygen and nitrogen.

The success in formulating and carrying out this study in different stages of its development was facilitated by M. A. Berezhkovskiy, S. V. Vasyukov, I. A. Kalinin, V. G. Klimovitskiy, V. M. Kondrat'yev, G. N. Levin, M. L. Libman, L. N. Ozerov, V. A. Pavlenko, V. G. Perminov, M. Ye. Slutskiy, S. I. Torbin, I. I. Chemeris, V. F. Shkurdod, Yu. A. Shul'chishin, O. N. Yakovlev and many others. The authors express deep appreciation to all of them.

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[429]

ANALYSIS OF THE CHEMICAL COMPOSITION OF THE VENUSIAN ATMOSPHERE ON THE AUTOMATIC INTERPLANETARY STATION "VENERA-12" USING A GAS CHROMATOGRAPH

Moscow PIS'MA V ASTRONOMICHESKIY ZHURNAL in Russian Vol 5, No 5, 1979 pp 217-221

[Article by B. G. Gel'man, V. G. Zolotukhin, N. I. Lamonov, B. V. Levchuk, L. M. Mukhin, D. F. Nenarokov, B. P. Okhotnikov, V. A. Rotin and A. I. Lipatov, Space Research Institute USSR Academy of Sciences and All-Union Scientific Research Institute of Multisided Automation of the Petroleum and Gas Industry, submitted for publication 26 February 1979]

Abstract: The paper gives a description of a chromatograph experiment carried out on the descent module of the automatic interplanetary station "Venera-12." Eight analyses were made of the chemical composition of Venus, beginning with an altitude of 42 km and to the surface of the planet. There was found to be nitrogen in a concentration 2.5±0.5% by volume, argon in a concentration $(4\pm2)\cdot10^{-3}$% by volume, CO in a concentration $(2.8\pm1.4)\cdot10^{-3}$% by volume and SO_2 in a concentration $(1.3\pm0.6)\cdot10^{-2}$% by volume. The upper limits for the content of oxygen and water vapor were estimated: $2\cdot10^{-3}$ and 10^{-2}% by volume respectively.

[Text] The "Sigma" gas chromatograph was installed aboard the descent module of the "Venera-12" automatic interplanetary station for investigating the chemical composition of the Venusian atmosphere. The distinguishing characteristic of the "Sigma" chromatograph is the use of a highly sensitive ionization detector (with a source of β-radiation). It is based on the Penning effect in rare gases (Rotin, 1974). The choice of the detector to a considerable degree determined the overall structure and metrological characteristics of the chromatograph.

Figure 1 is a block diagram of the "Sigma" chromatograph. The analysis of the gas sample and the calibration mixture were carried out using three sequentially placed columns and detectors. The first column, 2 m long, filled with modified polysorb, was intended for separation of the sulfur compounds H_2S, COS, SO_2 and water vapor in the carbon dioxide. In a second column, with a length of 2.5 m, with molecular sieves, there is separation of gases with a low boiling point -- helium, hydrogen, argon with oxygen, nitrogen, krypton, methane and carbon monoxide (Kiselev and Yanshin, 1967).

In order to determine the argon content we used a third column, a reactor with a length of 1 m with reduced manganese.

The response threshold for all three detectors in pure neon in a saturation current regime was at the level 10^{-5}% by volume, which ensured an analytical response at the level 10^{-4}% by volume with a volume of the working dose up to 1 cm^3 (Okhotnikov, et al., 1978).

The construction of the sampling unit precluded the possibility of the entry into the chromatograph of the gases released from the skin of the descent module. All the detector columns, and also the input reducer of the sampling unit, were placed in a special thermostat, whose temperature in the measuring regime was 70±1°. This same thermostat held electrometric amplifiers and voltage—frequency converters, which together with a source of d-c voltage constituted the measuring circuit of the ionization detectors.

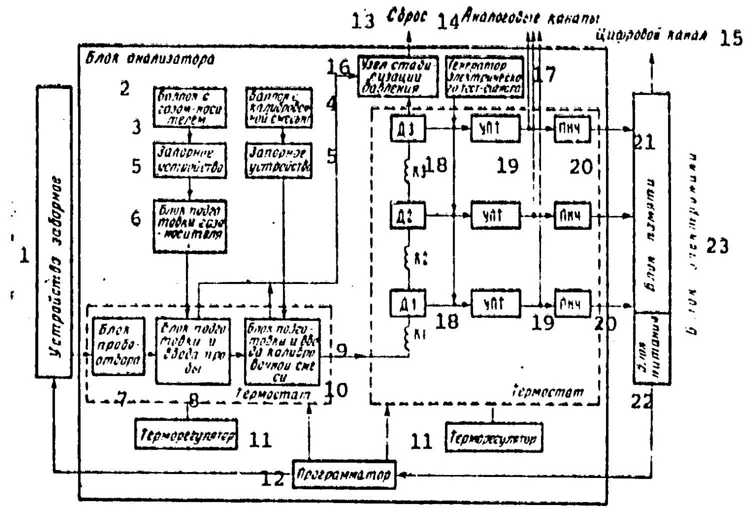
In connection with the high response of the ionization detectors to impurities in the carrier-gas some units in the chromatograph, after carrying out a cycle of surface calibrations, were sealed in order to prevent the inflow of contaminating gases during the storage period and testing and flight periods.

The program for operation of the "Sigma" chromatograph on the descent module of the "Venera-12" automatic interplanetary station included the following operations.

Approximately 4 hours prior to entry into the Venusian atmosphere the shut-off devices on the cylinder with the carrier-gas and the gas discharge line were opened, the thermostat for the columns was activated and for a period of four hours the chromatograph was scavenged by the carrier-gas. After entry into the dense layers of the atmosphere, during descent from 65 to 54 km from the planetary surface, the device for taking the samples was unsealed, the shut-off device on the line for the calibration mixture was opened and the analysis control cycle was prepared. At these altitudes the absolute pressure in the Venusian atmosphere was less than 1 kg/cm^2. Accordingly, for a control analysis no sample was taken from the atmosphere, but the carrier-gas with the contaminants present in the instrument was fed for analysis.

During descent of the descent module of the "Venera-12" station from an altitude of 42 km to the moment of landing there were a total of eight analyses of the planetary atmosphere. Fifty-four chromatograms were obtained. Eighteen of these corresponded to a determination of sulfur compounds and

27 corresponded to an analysis of gases with a low boiling point.



KEY:

1. Intake unit
2. Analyzer unit
3. Cylinder with carrier-gas
4. Cylinder with calibration mixture
5. Shut-off device
6. Unit for preparing carrier-gas
7. Sampling unit
8. Unit for preparing and input of sample
9. Unit for preparing and input of calibration mixture
10. Thermostat
11. Heat regulator
12. Programmer
13. Gas discharge
14. Analog channels
15. Digital channel
16. Unit for stabilizing pressure
17. Generator of electric test signal
18. Detector
19. Intermediate amplifier
20. Low-frequency converter
21. Memory unit
22. Power unit
23. Electronics unit

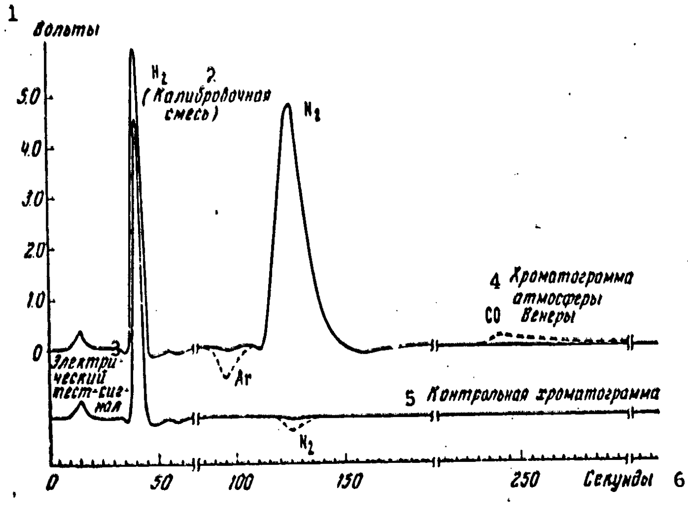


Fig. 2. Chromatogram of Venusian atmosphere. The dashed line defines peaks on the high response scale (exaggerated by a factor of 10).

KEY:
1. Volts
2. Calibration mixture
3. Electric test signal
4. Chromatogram of Venusian atmosphere
5. Control chromatogram
6. Seconds

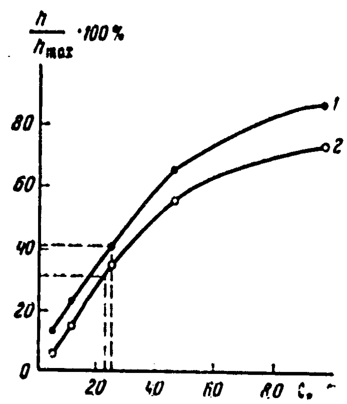


Fig. 3. Calibration curves of neon detector (relative to nitrogen). 1) regime of second detector, 2) regime of third detector

Компоненты 1	2 Концентрации объемных процентов	
	3 «Сигма»	4 «Пионер – Венера»
N_2	2.5 ± 0.5	$3.41-4.6$
H_2O	<0.01	$<0.06-0.5$
Ar	$(4\pm2)\cdot10^{-3}$	$(2\div3)\cdot10^{-3}$
CO	$(2.8\pm1.4)\cdot10^{-3}$	$<6\cdot10^{-3}$
SO_2	$(1.3\pm0.6)\cdot10^{-2}$	$1.86\cdot10^{-2}$
O_2	$<2\cdot10^{-3}$	$(5\div6)\cdot10^{-3}$

KEY:

1. Components
2. Concentration (in % by volume)
3. "Sigma"
4. "Pioneer-Venera"

Information on the results of a chromatographic analysis in analog form was transmitted through telemetric channels and simultaneously chromatograms of the first three analytical cycles were recorded in the instrument memory. The typical appearance of the chromatograms is shown in Fig. 2.

An analysis of a control chromatogram and chromatograms of the Venusian atmosphere reliably indicated the presence in the investigated samples not only of the main component -- carbon dioxide -- but also the impurities N_2, Ar, CO, SO_2. These components were identified from the retention times. Due to the partial oxidation of the manganese reactor the identification of argon was accomplished on the basis of the neon detector signal sign.

A quantitative interpretation of the registered chromatograms required allowance for change in the purity of the carrier-gas and contaminations of the gas lines in the chromatograph during the period of its storage and during the flight to the planet. An investigation of operation of the neon detector in a saturation current regime with different degrees of contamination of the carrier-gas indicated the possibility of distortions of the calibration curves in the threshold region of concentrations leading to the appearance of negative signals for substances with a high ionization potential: argon, nitrogen and sulfur gas. This peculiarity made it possible not only to identify the Ar peak, but also to check the calibration characteristics of the chromatograph under the same contamination conditions under which the instrument operated.

The calibration characteristics were checked with the working values of pressure, temperature and discharge of the carrier-gas. For the purpose of excluding the influence of activity of β-sources on the characteristics of the calibration curve the heights of the peaks of the substances to be analyzed were normalized to the values of the maximum signal of the detector relative to the hydrogen of the calibration mixture, CO_2 and N_2.

In an analysis of gases with low boiling points the second and third detectors duplicated the readings, although they had β-sources of different activity and operated under conditions of different contaminations. This circumstance made it possible to carry out independent computations of the studied components.

The heights of the nitrogen peaks on chromatograms of the Venusian atmosphere were 40 and 32% of the maximum signal for the second and third detectors respectively. Despite such an important difference, the measured nitrogen concentrations according to independent calibration curves coincided (Fig. 3). A similar method was used in checking the calibration curves for the remaining components.

The oxygen content could not be determined reliably due to partial oxidation of the manganese reactor. However, laboratory checking of the characteristics of the neon detector in the operating regimes of the "Sigma" instrument indicated that the negative signal from argon is reproduced only in a case when the oxygen concentration in the mixture is appreciably less than the argon concentration. Specifically this circumstance gives basis for assuming that the oxygen concentration in the Venusian atmosphere is at least less than $2 \cdot 10^{-3}$% by volume.

Due to the heavy overloading of the first detector the sulfur compounds should be manifested in the tail of the chromatographic peak of carbon dioxide. Therefore, for the quantitative computation of the concentration of the detected sulfur gas the normalized calibration curve was determined from an analysis of model mixtures prepared on the basis of carbon dioxide.

The results of an analysis of the Venusian atmosphere using the "Sigma" gas chromatograph are given in the table.

An estimate of the water vapor concentration in the planetary atmosphere caused some difficulties, since a control analysis indicated the presence of characteristic moisture in the instrument. As a result, a detailed analysis of the chromatograms makes it possible to indicate only the upper limit of the water vapor concentration. According to preliminary estimates, the moisture content in the Venusian atmosphere at all altitudes where the measurements were made is less than 0.01% by volume.

It is of interest to compare the results of the "Sigma" instrument and the AMS gas chromatograph aboard the "Pioneer-Venus" automatic interplanetary station (Oyama, et al., 1979). In general, the coincidence of the results is good, although there are two components for which there are considerable differences in the measured concentrations. These are oxygen and water vapor. The characteristics of the "Sigma" neon detector are such that in the range of argon concentrations $60 \cdot 10^{-6}$ its chromatographic peak is inverted. However, the oxygen peak in the entire measured range of concentrations is always positive. Therefore, if oxygen is present in a quantity $60 \cdot 10^{-6}$, a negative argon peak cannot be obtained on the "Sigma" chromatogram. This fact was established by laboratory experiments.

The water vapor content determined using the "Pioneer-Venus" gas chromatograph (up to 0.5%) is obviously exaggerated because the "Sigma" instrument surely would have registered such quantities of water vapor.

A refinement of the results of analysis of the concentrations of water vapor and oxygen, and also an identification of peaks hypothetically corresponding to the presence of hydrogen and carbon bisulfide, require computer processing of the chromatograms and additional laboratory modeling of operating conditions for the "Sigma" instrument. These investigations are now being carried out.

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[429]

SPECTROPHOTOMETRIC EXPERIMENT ON THE DESCENT MODULES OF THE "VENERA-11" AND "VENERA-12": SOME RESULTS OF ANALYSIS OF THE VENUSIAN DAYTIME SKY SPECTRUM

Moscow PIS'MA V ASTRONOMICHESKIY ZHURNAL in Russian Vol 5, No 5, 1979 pp 222-228

[Article by V. I. Moroz, B. Ye. Moshkin, A. P. Ekonomov, N. F. San'ko, N. A. Parfent'yev and Yu. M. Golovin, Space Research Institute USSR Academy of Sciences, submitted for publication 26 February 1979]

Abstract: The descent modules of the "Venera-11" and "Venera-12" during the course of descent in the atmosphere (from an altitude of 63 km to the surface) registered the spectra of the daytime sky of Venus in the range from 4500 to 12 000 A and the angular distribution of the brightness of scattered radiation (in four filters). The spectra show the absorption bands of CO_2, H_2O and some absorption in the blue-green part of the spectrum probably belonging to gaseous sulfur. An abundance $[H_2O]:[CO_2] \simeq 2 \cdot 10^{-5}$ was observed in the lower scale height region. If the identification of sulfur is correct, its abundance is $\sim 10^{-8}$ in this same region of the atmosphere. About 6% of the total solar flux reaches the planetary surface. The lower cloud boundary is situated at an altitude $\sim$47-48 km. The clouds have a layered structure.

[Text] Solar radiation penetrates into the deep layers of the Venusian atmosphere, despite its great optical thickness. It is repeatedly scattered in the cloud layer and the atmosphere beneath the clouds; direct solar radiation cannot be detected in the depths of the atmosphere, but scattered radiation can be rather intensive in some parts of the spectrum. An appreciable fraction of the flux reaches the surface and as a result, due to the great opacity of the atmosphere for thermal radiation, a strong greenhouse effect arises, which explains the high surface temperature.

An objective of the described experiment was measurement of the spectral and angular distribution of the energy of scattered radiation in dependence on altitude using an instrument carried aboard the descent module.

The interpretation of the experimental results will make it possible to solve problems of three types: 1) determination of the radiation influx of energy as a function of altitude, which is necessary for understanding the heat balance and atmospheric dynamics; 2) determination of cloud layer structure; 3) clarification of the nature of the different absorbing agents present in the Venusian atmosphere in the gas and aerosol phases.

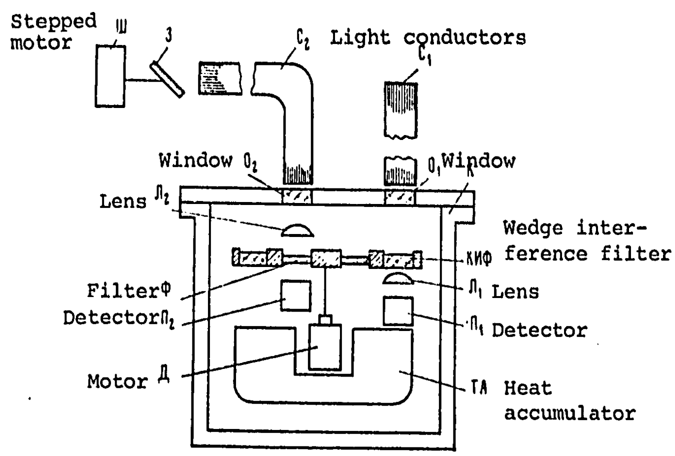

Fig. 1. Diagram of optical-mechanical unit (sensor) of spectrophotometer.

The first experiment with measuring the radiation flux in the deep layers of the Venusian atmosphere was carried out on "Venera-8" in 1972 (Avduyevskiy, et al., 1973). Measurements of the flux from above were made in a band with a width of about 2500 A centered at a wavelength of 6500 A. For the "Venera-9" and "Venera-10" two different groups carried out two different experiments for investigating the field of scattered radiation in the atmosphere. In one of them (Avduyevskiy, et al., 1976; Ekonomov, et al., 1978) measurements were made of the fluxes from above and below using five broad (~1000 A) filters covering the interval from 0.5 to 1.2 μm. In the second experiment (Moroz, et al.) measurements were made of the intensity of radiation with three narrow (~50 A) filters centered on the CO_2, H_2O bands and the segment of the continuous spectrum in the interval 8000-9000 A.

The efforts and experience of both groups were combined in preparing the new experiment aboard the "Venera-11" and "Venera-12." As a result, a new instrument was created having essentially new possibilities (Fig. 1). The instrument consists of two functional units -- spectrometer and scanning photometer. The radiation enters the spectrometer through a flexible light conductor C_1 receiving radiation from the zenith region at an angle of about 15°. It passes through a sealed window O_1, a wedge interference filter WIF and by the lens L_1 is collected by the detector D_1 (germanium photodiode). The ring-shaped wedge interference filter consists of two half-rings, one of which analyzes the region from 4500 to 7000 A with a resolution of about 200 A, the second -- the region from 7000 to 12 000 A with a resolution of about 400 A. The external diameter of the filter is 50 mm. A disk with a wedge filter rotates with a period of 10 sec; it is driven into motion by a motor M through a reducer. In the same disk as the WIF there are four wide glass filters F made in the form of sectors of 90° and discriminating broad spectral intervals centered at 4900, 7100, 10 000 and 13 000 A. The radiation received by the scanning photometer passes through these filters and the lens L_2 and reaches the detector D_2. The scanning is accomplished in the vertical plane and is accomplished by the rotation of the slanted mirror M about the horizontal axis, use being made of a high-temperature stepped motor SM.

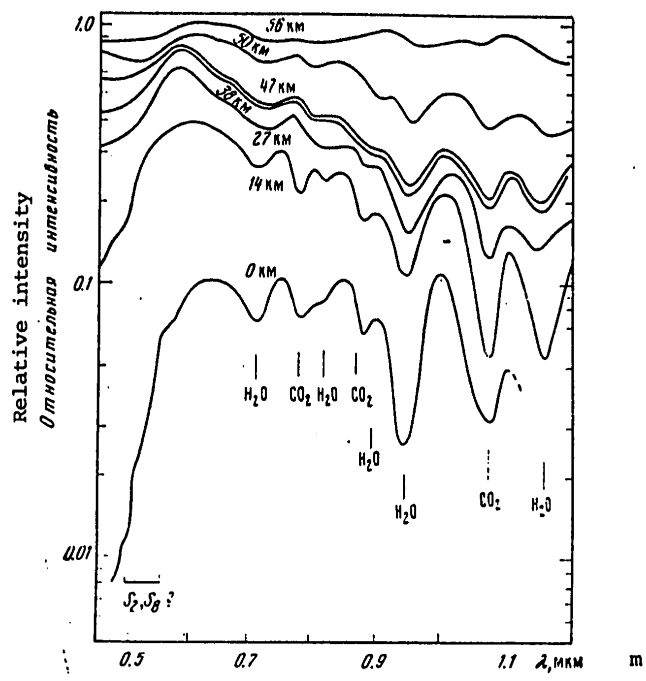

Fig. 2. Normalized spectra of scattered solar radiation in depths of the Venusian atmosphere at different altitudes above surface. Along x-axis -- wavelength, along y-axis -- relative intensity (as a standard in normalization use was made of the spectra at altitudes 63-65 km). The figures near the curves represent altitude above the surface.

The radiation reflected from the mirror Mir is directed to the window O_2 through the light conductor C_2. The scanning period is about 1.5 sec.

The container Con was mounted on the outside of the descent module and was rated for operation under the conditions prevailing in the Venusian atmosphere down to the surface (100 atm, 750°K); assurance of the thermal regime is accomplished autonomously (heat insulation and heat accumulator HA). The container protects the main optical elements and the preamplifier housed in it; its internal volume is about 0.5 liter. The main part of the electronic circuit (amplifiers and converter) is situated in the electronic unit within the descent module. We note that for investigating the radiation field in the depths of the Venusian atmosphere the American craft "Pioneer-Venus" made use of a more primitive instrument, in general, similar to the wide-band photometer on the "Venera-9" and "Venera-10."

As a result of the carrying out of experiments aboard the "Venera-11" (25 December 1978) and the "Venera-12" (21 December 1978) it was possible to obtain approximately 300 spectra and angular scans for each vehicle, with total spectrophotometric sounding of the Venusian atmosphere from an altitude $\sim$65 km to the surface. The measurements were made near the equator with a solar zenith distance $\sim$20°. More detailed information on the characteristics of landing sites are given in the communicattion "First Results ..." (Barsukov, et al., 1979). The descent from an altitude of 65 km to the surface lasted 62 minutes.

In the stage of preliminary processing we used as a standard the spectra obtained in the upper part of the cloud layer.

The spectral intensities within the range of $\sim$10-20% do not differ (except for the blue part of the spectrum) from those which would be characteristic of the radiation reflected from a Lambert screen illuminated by the sun. Figure 2 shows some characteristics of spectra related to this conditional standard. The spectra are given schematically. We have not shown some faint details whose reality requires additional checking. The altitude tie-in is preliminary.

The intensity of the radiation is attenuated with descent at all wavelengths to an altitude of 47-48 km, that is, within the cloud layers. Weak but entirely reliable depressions which are gradually intensified can be seen. These are the absorption bands of CO_2 and H_2O and some absorption in the blue part of the spectrum.

After passage through the level 47-48 km the spectral changes (both in absolute value and in distribution) cease for some time. The spectra at altitudes of 38 and 47 km are virtually identical. We attribute this to being a result of emergence from the cloud layer. The first 10 km of the atmosphere under its lower boundary almost add nothing to the measured intensity. On the "Venera-9" and "Venera-10" the lower boundary of the cloud layer was registered (Avduyevskiy, et al., 1976; Marov, et al., 1976; Moroz, et al., 1976; Ekonomov, et al., 1978) at a close altitude (49-50 km), but below the boundary there was some weaker scattering medium.

Below 38 km and to the surface the intensity of the CO_2 and H_2O bands systematically increases. In addition, a steep drop appears in the blue-green spectral region -- stronger than Rayleigh scattering can give. We can mention several molecules -- gaseous sulfur, Br_2, NO_2 -- which with a very small abundance (10^{-8}-10^{-9} relative to CO_2) can be responsible for this absorption.

As a first step in the interpretation of data obtained in the spectrophotometric experiment aboard the "Venera-11" and "Venera-12" it was decided to carry out an analysis of the transmission spectrum for the atmosphere below the clouds. The measured dependence of the ratio of intensities at altitudes 0 and 47 km on wavelength (reference is to the planetary surface and the lower boundary of the cloud cover) was compared with the computed dependence for the following model: a homogeneous CO_2 layer with an admixture of a small quantity of H_2O (variable parameter in the model), pressure in the layer equal to pressure at the surface (91 atm), thickness of the layer equal to the altitude of the homogeneous atmosphere. The transmission of such a layer for a diffuse source is equal to

$$\rho_T = \rho_0(\bar{\mu}, \mu_2, a, \tau_0) + \frac{AVF}{1-AW} + e^{-\tau}\left(1 + \frac{AV}{1-AW}\right),$$

where $\bar{\mu} = 0.7$ is the mean value of the cosine of the angle of incidence, $\mu_2 = 1$ is the cosine of the sighting angle (the optical axis of the spectrophotometer was oriented to the zenith), $a = \sigma/(\sigma + k)$ is the albedo of single scattering, $\sigma = 8.07 \cdot 10^{-7} \lambda^{-4}$ cm^{-1} is the coefficient of Rayleigh scattering for CO_2 (λ is wavelength in μm), k is the total absorption coefficient (CO_2, H_2O, S_2+S_8, etc.), τ is the optical thickness, $\rho_0(\bar{\mu}, \mu_2, a, \tau)$ is the brightness coefficient for scattered radiation, $e^{-\tau}$ is the brightness coefficient for direct radiation attenuated by extinction, A is albedo of the surface. The optical thickness of the layer τ_0 for Rayleigh scattering varies in the range, approximately, from 0.8 (λ = 12 000 A) to 40 (λ = 4500 A). The terms including AV/(1 - AW) take into account re-reflection between the surface and the gas layer. The corresponding auxiliary functions V, W, F were computed using the asymptotic formulas of scattering theory cited in a study by Danielson, et al. (1969). The $\rho_0(\bar{\mu}, \mu_2, a, \tau_0)$ values were computed by two methods: first -- computations using the rigorous formulas of the theory of multiple scattering of light using the Chandrasekar auxiliary functions for the Rayleigh indicatrix $x(\gamma) = 3/4(1 + \cos^2\gamma)$ and second -- computations using the asymptotic formulas published by Danielson, et al. (1969) on the assumption of a spherical indicatrix. Both methods give extremely close results when $a > 0.95$ and $\tau > 4$. With lesser τ and a values use was made of ρ_0 obtained by the first method; the second method was used primarily for extrapolation into the region of large τ, for which there are no tabulated data for the X-, Y-functions (the Sweigart tables, 1970, were used).

The CO_2 absorption coefficients were taken using the computations of Gal'tsev and Osipov (which served as a basis for a study by Gal'tsev, et al., 1976). For the H_2O absorption coefficients we did not find the necessary data in the literature ($\lambda < 1.2\ \mu$m, temperature 700-750 K and high pressures). We measured these absorption coefficients in the laboratory using a high-temperature absorption cell with a length of 1 m with a H_2O content on the line of sight 0.36 g·cm^{-2} and a spectral resolution from 4 to 8 A. The pressure in the cell was ~12 atm, which from the point of view of line broadening satisfactorily simulates the lower atmosphere of Venus (the self-broadening coefficient for H_2O relative to CO_2 is about 4 and the width of the lines in our cell should be the same as in the Venusian atmosphere at an altitude of approximately 10 km). The rotational structure of the H_2O bands in the lower layers of the Venusian atmosphere should be strongly smoothed, and in the CO_2 bands -- virtually absent.

A comparison of measurements with model computations (made with 50 A averaging) indicated that within the limits of lower scale height of the Venusian atmosphere

$$[H_2O] : [CO_2] \simeq 2 \cdot 10^{-5}.$$

Some uncertainty in the estimate is attributable to the neglecting of the rotational structure of H_2O and inaccuracies in the employed values of the coefficients of continuous absorption of CO_2 caused by the wings of the distant bands. We are convinced that the true abundance of H_2O differs by no more than a factor of 2 from that cited above. Our result does not coincide with the results of measurements on "Pioneer-Venus" (Oyama, et al., 1979), according to which at an altitude of 34 km there is 0.5%, and at an altitude of 24 km -- 0.135% H_2O. There is assurance that with a H_2O content of 0.1-0.5% the spectrum of the atmosphere below the clouds would have a completely different form. According to preliminary estimates obtained on the basis of our spectra, the H_2O content in the Venusian atmosphere at any altitudes does not exceed a level of about 10^{-4}.

Absorption in the region $\lambda < 6000$ A is most satisfactorily attributable to the absorption of gaseous sulfur, although the possibility of a contribution of other molecules (such as Br_2, NO_2) also cannot be precluded. The poorly expressed but probably real structure of the measured spectrum which exists in this region agrees with sulfur. We carried out laboratory measurements of the absorption of gaseous sulfur at temperatures 600-800 K and obtained spectra which show similar details. If this identification is correct, then the relative abundance is

$$\frac{[S_2] + [S_4] + [S_6] + [S_8]}{[CO_2]} \simeq 10^{-8}.$$

We note that with the indicated temperatures all the enumerated modifications of sulfur are present. Such low estimates for the content of gaseous sulfur in the atmosphere beneath the clouds probably create difficulties for hypotheses attributing "UV" absorption in the clouds to the presence of the sulfur condensed there (Young, 1977). If we set aside the mentioned faint details in the measured spectrum, the "blue dropoff" can also be attributed to the presence of bromine molecules with a relative abundance of 10^{-10} and NO_2 of approximately $3 \cdot 10^{-10}$. In any case, the mentioned abundances of sulfur, bromine and NO_2 can be regarded as the upper limits.

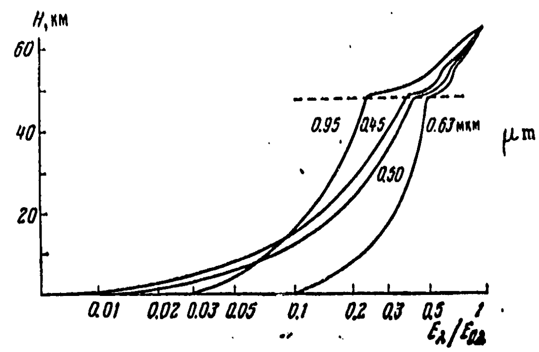

Fig. 3. Normalized intensity as a function of altitude for several wavelengths. The dashed line represents the lower boundary of the cloud layer.

In the region from 6000 to 7000 A the albedo of single scattering in the Venusian lower atmosphere is in the range from 0.999 to 1.000. In this sector about 10% of the sunlight reaches the surface. The fraction of the total (integrated in the spectrum) solar flux reaching the surface is about 6%.

Figure 3 schematically shows the dependence of intensity at the zenith for several wavelengths on altitude (also on the basis of spectrometer data). In addition to the sharp lower boundary of clouds it is possible to see intermediate boundaries, evidently reflecting the complex vertical structure: at least three layers can be discriminated there. The mentioned presence of some vertical structure in the clouds was noted earlier in the experiments on the "Venera-9" and "Venera-10" (Avduyevskiy, et al., 1976; Marov, et al., 1976; Moroz, et al., 1976). An analysis of the data on cloud cover characteristics obtained in this experiment will be presented in subsequent communications.

The preliminary results cited here demonstrate the possibilities of the spectroscopic method in application to the chemical analysis of the Venusian lower atmosphere. Even with a resolution of 200-400 A for some components it is possible to obtain responses of 10^{-10}-10^{-8}, which cannot be achieved with on-board mass spectrometers and gas chromatographs. An increase in resolution by an order of magnitude considerably broadens these possibilities.

The contradictions with respect to H_2O are not limited to the discrepancy between the American chromatograph and our spectrophotometer. Up to 2% H_2O was obtained using chemical gas analyzers aboard the "Venera-4," "Venera-5" and "Venera-6" (Vinogradov, et al., 1970). These results seem to be questionable, but in principle the possibility of strong local and temporal variations is not excluded. There is a need for further investigations with the use of some standard and absolutely reliable method. As indicated by available experience, with the use of direct chemical analyses a spectrophotometric control will be very useful.

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[Note added during correction: An estimate of the upper limit of content of Cl molecules was obtained in a further analysis. It is about 10^{-8} relative to CO_2.]

[429]

ELECTRIC DISCHARGES IN THE VENUSIAN ATMOSPHERE

Moscow PIS'MA V ASTRONOMICHESKIY ZHURNAL in Russian Vol 5, No 5, 1979 pp 229-236

[Article by L. V. Ksanfomaliti, N. M. Vasil'chikov, O. F. Ganpantserova, Ye. V. Petrova, A. P. Suvorov, G. F. Filippov, O. V. Yablonskiy and L. V. Yabrova, Space Research Institute USSR Academy of Sciences, submitted for publication 26 February 1979]

Abstract: The article gives a preliminary analysis of some results obtained when measuring the electric activity of the Venusian atmosphere aboard the descent modules of the "Venera-11" and "Venera-12." For the first time it was possible to register the low-frequency electromagnetic radiation of the Venusian atmosphere, evidently associated with electric discharges in the cloud layer situated at altitudes 50-70 km. The energy in the discharges is of the order of magnitude of the energy released in discharges of terrestrial lightning. The extent of one of the thunderstorm regions was close to 150 km horizontally and 2 km vertically. The mean frequency of recurrence of the discharges attained 20 sec^{-1} or more, which greatly exceeds the frequency of discharges in terrestrial thunderstorms. During the period of the investigations thunderstorm phenomena on Venus had a local, nonglobal character.

[Text] One of the problems investigated in the study of Venus is the origin of small components of its atmosphere, including those containing sulfur. The role of thunderstorm electric discharges in the formation of such components of the earth's atmosphere as nitrogen oxides, ozone and others is well known. It has also been established that in the early stage of evolution of the earth's atmosphere the discharges led to the appearance of primitive organic compounds. It can be postulated that thunderstorm discharges can play an important role in formation of small components in the Venusian atmosphere. Favorable conditions for the accumulation of charges create intensive movements at the level of the cloud layer of Venus.

The purpose of one of the experiments on the descent modules of the "Venera-11" and "Venera-12," which received the name "Groza," was an investigation of the electric activity in the planetary atmosphere ("First Results...," Ksanfomaliti, et al., 1979). During the period of preparation of the experiment, independently of us, Hara (1976) presented the idea of probable thunderstorm activity on Venus.

The "Groza" instrument represented a miniaturized superlong-wave spectrum analyzer operating in the range 8-100 KHz with a high threshold response supplied with an external loop antenna. There were four frequency channels: 10, 18, 36 and 80 KHz with bands with a width of 1.6, 2.6, 4.6, 14.6 KHz respectively. The spectrum analyzer was supplied with two integral discriminators with scaling devices for 64 and 256 units, with an AVC unit and built-in calibration. We note that some initial data were absent in the preparation of the experiment. The instrument was activated at an altitude of about 60 km and operated during descent and at the planetary surface after the landing.

Radio noise extremely similar to the terrestrial atmospheric radio noise arising during thunderstorm electric discharges was registered. Comparison of the development of radio noise bursts during descent of the two vehicles along identical paths in one and the same region of the planet is possible on the fragment of the telemetric record in Fig. 1. The graphs were constructed as a function of Moscow time of reception of information at the earth. Along the vertical we have plotted field strength in each of the frequency channels. Due to the compressed horizontal scale and small time constant of the instrument (0.24 sec) the registered discharges have the form of vertical lines. During the descent of "Venera-11" the thunderstorm phenomena were extremely intensive, with frequent discharges, whereas during the descent of the "Venera-12" the thunderstorm conditions were calmer. In order to avoid misunderstanding, we note that in speaking about a thunderstorm we have in mind only electric discharges in the atmosphere similar to terrestrial lightning, and not the falling of any precipitation. Figure 1 clearly shows the development of a large burst consisting of thousands of individual discharges. The telemetric records contain a large number of such phenomena. Of particular interest are groups of bursts which passed from the frequency channels 80 and 36 KHz into the channels 18 and 10 KHz with a delay of several minutes. Under the conditions of an extremely weak dipole magnetic field of Venus such a delay requires special explanation. The strength of the electromagnetic field of radio noise at altitudes less than 3 km and at the surface was, with one exception, very small, which can be attributed to radiorefraction in the dense atmosphere of Venus. This was first mentioned by V. V. Andreyanov, to whom the authors express appreciation for useful discussion.

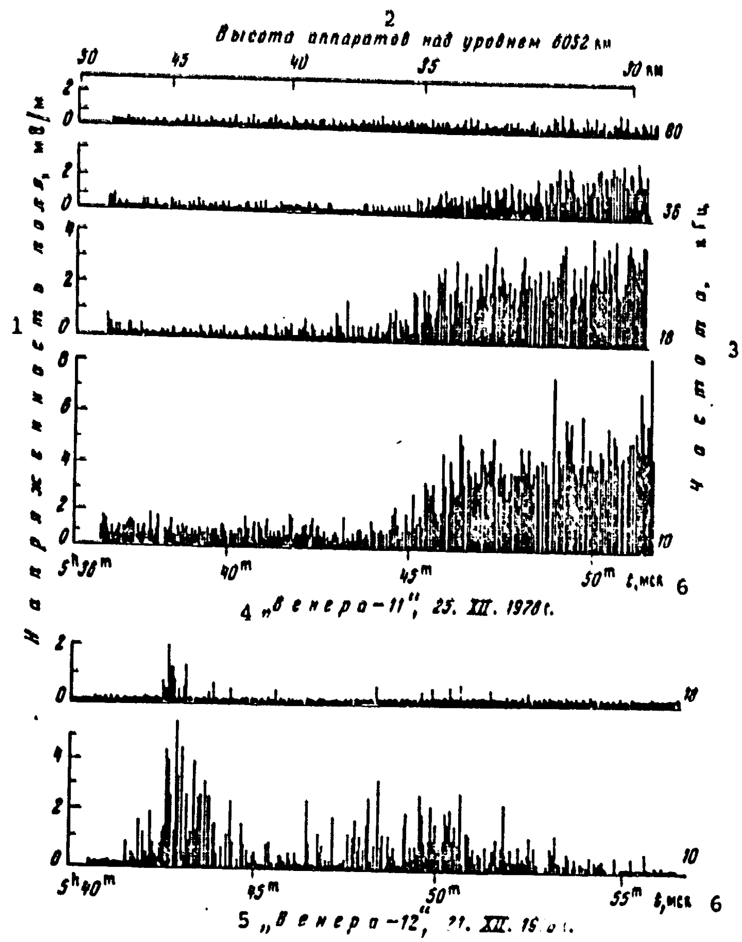

Fig. 1. Comparison of registered electric activity of the Venusian atmosphere during the descent of the "Venera-12" (two lower graphs) and "Venera-11" (four upper graphs) vehicles. The altitude scale applies to both vehicles. The signal was registered in the bands 1.6, 2.6, 4.6 and 14.6 KHz at frequencies 10, 18, 36 and 80 KHz respectively.

The noise associated with electrification of the vehicles during their motion was insignificant. This is confirmed both by the similarity of the phenomena during the descent of the two vehicles and the many peculiarities of the telemetric records.

The processing of the experimental results has still not been completed. Accordingly, the data cited in the article must be regarded as preliminary.

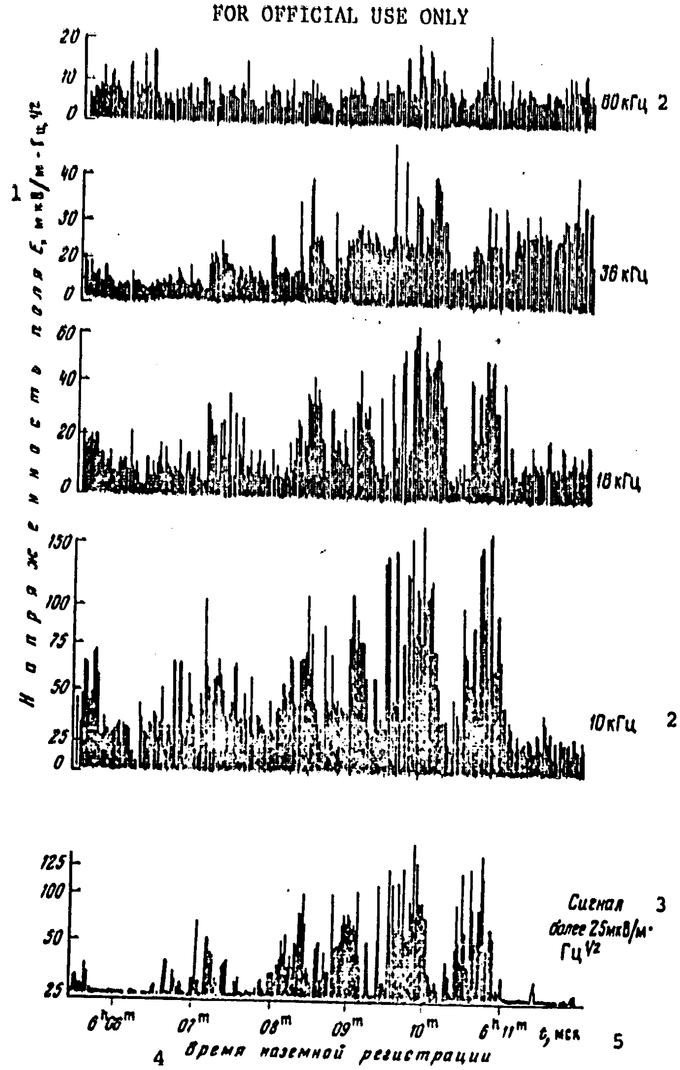

Fig. 2. Periodic sequence of radio noise bursts registered by "Venera-11" at altitudes 7-13 km.

KEY:

1. Field strength E, $\mu V/m \cdot cps^{1/2}$
2. KHz
3. Signal more than 25 $\mu V/m \cdot cps^{1/2}$
4. Time of surface registry

Preliminary analysis of radio noise bursts. Now we will discuss one of the unexpected but extremely interesting experimental results. Among the numerous groups of bursts registered by "Venera-11" is a sequence characterized by a periodicity conspicuous even to the eye (Fig. 2). This group was registered from 0604 to 0611 hours. The altitudes through which the vehicle passed during this time were from 17 to 13 km. It consists of six large bursts following one another with an increasing amplitude. In each packet there were several hundred impulses corresponding to individual discharges. The first three bursts were separated by intervals of about 90 and 80 sec and the subsequent bursts were separated by intervals of 50 sec. The entire sequence ends with a sudden disappearance of the signal after 0611 hours. This part of the trace was particularly productive. As indicated below, the successful combination of altitude of the vehicle and the position of the source made it possible to find the most important parameters of a Venusian thunderstorm with a minimum of assumptions.

L. V. Ksanfomaliti postulated that the origin of this sequence is associated with slow rotation of the vehicle during descent, which is attributable to aerodynamic factors. A comparison of the periodicity of the bursts with the measured angular velocity of rotation of the vehicle ω_x about the vertical axis confirmed the correctness of this assumption: ω_x varied in the range from 2 to 7 degrees/sec, which makes the half-period of rotation from 90 to 26 sec. The directivity characteristic for the loop antenna used in the instrument is described by the following function:

$$F(\theta) = \sin\theta, \qquad (1)$$

where θ is the angle between the normal to the plane of the loop and the direction to the signal source. If the antenna is situated in the vertical plane and the azimuthal angle of the source is α, the voltage across the output of the loop antenna with the effective altitude H with a field direction E is

$$U = EH\sin(\omega_x t + \alpha). \qquad (2)$$

In this case, the rotation of the vehicle should lead to intense modulation of the signal received from the point source situated at approximately the same altitude as the receiver.

The real situation, of course, is more complex. The antenna is situated in such a way that the loop forms an angle of 45° with the horizontal plane of the vehicle and its diagram is somewhat distorted by the influence of the vehicle. Moreover, it is difficult to visualize a powerful source of radio noise having such a small extent that it can be considered a point source. However, such an assumption was expressed in connection with the hypothesis of Venusian volcanism. During strong eruptions of volcanoes on the earth numerous lightning discharges are observed over them. But since for the time being nothing is known concerning volcanic activity on Venus, we will attempt to explain the observed phenomenon from the point of view of thunderstorm activity in the Venusian atmosphere.

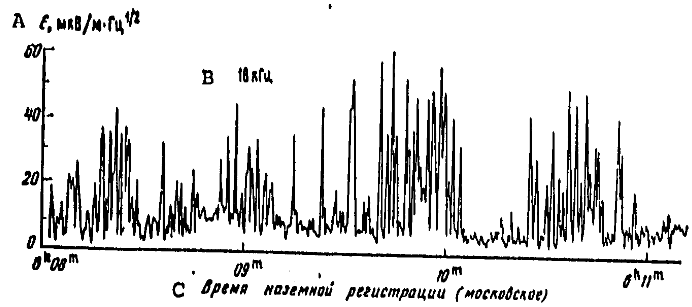

Fig. 3. Same as in Fig. 2, for the channel 18 KHz at an exaggerated time scale.

KEY:

A. E, $V/m\cdot cps^{1/2}$
B. KHz
C. Time of ground registry (Moscow time)

First of all we will ascertain the angular dimensions of the source. An analysis of the telemetric information shows that in the intervals between bursts the field strength is not equal to zero (Fig. 3). It goes without saying that this can be the background from other sources, but during the period from 0604 to 0612 hours at the margins of the described group of bursts the background was very low. A study of records similar to Fig. 3 shows that at frequencies of 10 and 18 KHz the minimum level of radio noise U_{min} between the bursts was 5-8 $\mu V/m\cdot cps^{1/2}$. Taking into account the symmetric two-lobe form of the antenna directional diagram, it is possible to find the approximate angle at which half the source is observed:

$$\delta = \arcsin \frac{U_{min}}{2U_{max}}, \quad (3)$$

which gives δ = 1.4-3.8° or on the average 2.6°.

Distance to source of bursts. In the propagation of superlong waves in the earth's atmosphere a major role is played by the "ionosphere-surface" waveguide. The presence of a sufficiently dense ionosphere on the daytime side of Venus also should seemingly lead to distant propagation of radio waves in the superlong-wave range. At the same time, both vehicles detected a marked decrease in the strength of the electromagnetic field at the planetary surface, which can be associated with some mechanism of radio wave absorption. Proceeding on this basis, we will examine only a direct wave when the main role in the reception of radiation is played by the altitude of the source above the surface and strong refraction in the dense atmosphere. The greatest altitude at which discharges can occur is not higher than the lower boundary of the ionosphere, which is found at the level 90-100 km using radio refraction experiments on space vehicles. However, it is more probable that the source of radio noise (lightning) is situated in the cloud layer, whose upper boundary, according to Ksanfomaliti (1977), corresponds to a level of 71 km.

Since both the source and the vehicle are situated in the atmosphere, a direct wave is propagated between them; this wave is not attenuated by the surface. In this case the field strength E from a discharge with the energy W, occurring during the quite short time , can be computed approximately in accordance with theory (Feynberg, 1961) in the following way:

$$E \propto \frac{\sqrt{W/\tau}}{R} \sin \vartheta, \qquad (4)$$

where R is the distance between the source and detector, and ϑ is the angle between the line of the source dipole and the direction to the detector.

We will examine possible variants of the position of a source of bursts. In the first variant the source is situated close -- in accordance with the position of the antenna in a plane passing through the vehicle and inclined 45° to the horizon. Three cases are possible: the source is situated in the cloud layer; then the distance to it is $R_1 = \sqrt{2}$ (70-15) = 78 km, at the surface, then $R_2 = \sqrt{2} \cdot 15$ = 21 km or also at intermediate altitudes. (We recall that 15 km is the mean altitude of the vehicle during the registry of signals from this source of bursts).

The second variant is characterized by a distant position of the source (at the radio horizon). The criterion for choice between these variants can be a comparison of the energy in a single discharge with the data known from an analysis of terrestrial thunderstorms. The energy of terrestrial lightning is assumed equal to $W_0 = 10^8$J, which corresponds to the potential difference $75 \cdot 10^6$V and a transfer charge 1.3 Kl. We will also assume that τ is constant (for terrestrial thunderstorms ~100 μsec).

The spectral field strength from lightning discharges in the earth's atmosphere is analytically expressed complexly. Frequently use is made of an averaged model of lightning, reflecting the mean figures for the spectral density of its radiation (Yuman, 1972; FIZ. ENTSIKLOPEDICHESKIY SLOVAR' (Physical Encyclopedic Dictionary), 1960). Such a model is shown in Table 1, which also includes the results of measurements for the considered case.

The energies in a discharge ensuring the strengths given in Table 1 were found from (4) as

$$W_{1,2} = W_0 \left(\frac{E_{\text{изм}} R_{1,2}}{E_0 R_0} \right)^2 \qquad (5)$$

[изм = meas] and are given in Table 2.

Such small energies in a discharge, thousandths or ten-thousandths of the energy of terrestrial lightning (Yuman, 1972; Imyanitov, et al., 1971), are questionable. A breakdown voltage in carbon dioxide requires somewhat greater values than in the air. With respect to the aerosol medium, it determines only the accumulation of charges in the clouds, but not the mechanism of the discharge itself, which is identical both in air and in carbon dioxide. Therefore, it is logical to expect an energy in the discharges of the same order of magnitude as in terrestrial lightning.

Precisely such a result is given by the second variant, when the source is situated at the radio horizon. Once again we use Table 1 and compute the ranges

$$R_s = E_0 R_0 / E_{\text{изм}}, \tag{6}$$

[ИЗМ = meas] proceeding from an energy in the discharge equal to 10^8J. The determined distances are given in Table 3.

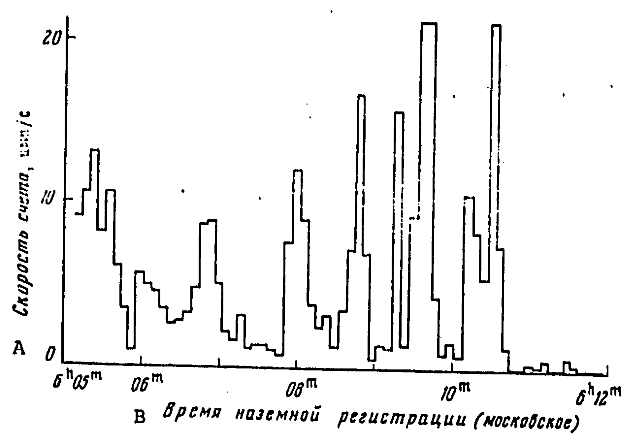

Fig. 4. Histogram of counting rate of pulses in channel of integral discriminator corresponding to Fig. 2.

KEY:
- A. Counting rate, pulses/sec
- B. Time of ground registry (Moscow time)

If the source was actually so distant, about 1,800 km, will it be situated on the radio horizon?

Radio horizon range. If the altitude of the vehicle h and the signal source z is 15 and 70 km respectively, the distance to the radio horizon when the planetary radius is a = 6,052 km, in accordance with the formula for direct visibility (Chernyy, 1972), is equal to

$$R = \sqrt{2a}\,(\sqrt{z} + \sqrt{h}) = 1347 \text{ км.} \tag{7}$$

Table 1

Frequency, KHz	10	18	36	80
Field strength E_0 at standard distance from source $R_0 = 10$ km, $V/m \cdot cps^{1/2}$ (earth)	$20 \cdot 10^3$	11.10^3	$5.6 \cdot 10^3$	$2.5 \cdot 10^3$
Measured strength E_{meas}, $\mu V/m \cdot cps^{1/2}$ (Venus)	110	60	33	12

Table 2

Frequency, KHz	10	18	36	80
W_1/W_0	$1.8 \cdot 10^{-3}$	$1.8 \cdot 10^{-3}$	$2.1 \cdot 10^{-3}$	$1.4 \cdot 10^{-3}$
W_2/W_0	$1.3 \cdot 10^{-4}$	$1.3 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$	10^{-4}

Table 3

Frequency, KHz	10	18	36	80	Mean
R_3, km	1820	1837	1687	2088	1858

The value of the refraction angle was computed on the basis of the distribution of the density of the Venusian atmosphere with altitude, cited in Kuz'min and Marov (1974). The computation method and the results will be presented in another article. Here, without giving the derivation, we give the following result: if the vehicle is situated at an altitude of 15 km, the maximum refraction angle for a ray reaching the level 70 km is 3°, which gives an increase in range by 160 km for a radius of 6,120 km. Thus, the total distance to the radio horizon is 1,510 km, which within the limits of accuracy in our computations coincides well with the mean value in Table 3.

Now we will return to Figures 2 and 3. The series of bursts is cut off sharply at 0611 hours. Such a nature of signal changes is attributable most simply specifically to the withdrawal of the source beyond the radio horizon.

Thus, three circumstances indicate the position of the source of bursts: coincidence of the energy in the discharge with the known value for terrestrial lightning; distance to the radio horizon, coinciding with the computed range of the source, and total disappearance of the signal, corresponding to its "radio setting."

The radio noise bursts indicated in Figures 2 and 3 also made it possible to find a number of other parameters of a Venusian thunderstorm. The structure of the bursts makes it possible to conclude that all the impulses are from the same source. Figure 4 shows a histogram of the pulse counting rate. It follows from this figure that the mean frequency of the discharges in one source is very high and attains 20 pulses/sec, which greatly exceeds the similar parameter for terrestrial thunderstorms. Other parts of the telemetric record give still greater frequencies.

The range and the angular dimensions of the source found above make it possible to estimate its extent: 150 km, which is an extremely extended thunderstorm front. From the duration of the radio setting and the descent velocity of the vehicle it is easy to find the altitude of the thunderstorm layer 1-2 km. Finally, Figure 3 gives an opportunity to evaluate the statistical dispersion of the energy in the discharges, assuming τ to be constant. The similarity of pulse amplitudes indicates that all the discharges probably occur in the cloud layer between its individual parts. Then the energy W and the distance R_3 will be somewhat less and the coincidence of the computed range and the radio setting will be still more convincing.

Proceeding on the basis of the great total number of discharges per unit time in the Venusian atmosphere and their considerable energy it appears probable that the glow of the nighttime side of Venus which is sometimes observed is attributable to an increase in thunderstorm activity.

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SHORT-RANGE FORECASTING OF SOLAR FLARES

Moscow VESTNIK AKADEMII NAUK SSSR in Russian No 5, 1979 pp 59-64

[Article by V. V. Migulin, Corresponding Member USSR Academy of Sciences, Candidate of Physical and Mathematical Sciences M. M. Molodenskiy and Doctor of Physical and Mathematical Sciences S. I. Syrovatskiy]

[Text] The problems involved in the prediction of solar chromospheric flares are extremely diverse and the prospects for their solution are different. The long-range (up to several months) forecasting of flares is the most difficult of these problems, for the time being having almost no theoretical basis. This is attributable to the fact that at the present time we do not have a possibility of indicating the time and place of the appearance of a new active region on the sun. Accordingly, it is necessary to turn to a search for statistical patterns on the basis of the collected information. In solving this problem for the time being it has not been possible to proceed significantly beyond the construction of synoptic maps and defining of active longitudes. (It should be noted that for the time being in our country there are no observatories which with sufficient routineness issue such information, despite the fact that some stations occupied by the sun service could do this).

The most long-range forecast (for several years or the entire next cycle) is prepared on the basis of highly averaged data. Therefore, the problem of such forecasting is less complex.

An approach having adequate theoretical and experimental basis can be used for short-range (from several hours to one day). This problem differs from the first very, very substantially. Whereas for the first problem (preparing a forecast for a time including the appearance of a new active region), for a short-range forecast we have all the necessary information. Since flares owe their origin to a magnetic field, observational data on the magnetic field and its evolution, and also a knowledge of the flare mechanism make possible the theoretical computation of development of the phenomenon. In addition, for this forecast it is possible to obtain additional information -- from observations of the structure of an active region (and its changes) in the Fraunhofer lines Hα, K-Ca II and others. This structure is determined by the magnetic field at the level of line formation.

Such in broad outlines is the fundamental aspect of the problem. For the time being the practical results leave much to be desired. At the present time only the prognostic center at Boulder in the United States and the Meudon Observatory in France collect data for short-range forecasting and make some attempts at such forecasting. However, the forecasting method is still exceedingly far from the development of clear algorithms and obtaining the quantitative characteristics of the probabilities of flares. The difficulty is not that a great number of parameters must be taken into account for the corresponding computations, but primarily that the approach itself for the time being has a purely synoptic character and there have not even been attempts to apply the completely reliable theoretical principles. Under these conditions the synoptic and statistical methods of a so-called quantitative forecast, based on the theory of recognition of objects or approximation of phenomena, are unpromising since it is necessary in advance to lay aside an evaluation of the weights of those characteristics on the basis of which the image to be identified is created. Therefore, in this case as well it is most important to discriminate from the great volume of information that part of it which is important for the prediction of flares. This is clearly a theoretical problem. With refinement of theory the range of the necessary information can be broadened, but now it is necessary to combine theory and observations on the basis of already available theoretical principles and the practice of observations of the development of active regions.

In order to advance further both in the forecasting problem and in the theory of flares itself there must be a clearer classification of the basic principles on the basis of which the modern theory is developed. It is useful to introduce evaluations of the basic principles of the theory, classifying them as: 1) reliable, 2) probable, 3) possible. The following principle can now be classified as reliable.

A solar chromospheric flare is a process of sudden transformation of magnetic energy into forms which can be directly observed. As is well known, flares occur only in active regions. We do not know of even a single case of a flare in the undisturbed chromosphere. Since this principle is unquestionable, it is necessary to adopt another principle which is not less reliable than the preceding one. It is as follows. [See footnote]

The potential field has the minimum energy among all the fields with a stipulated normal component on the boundary of the region occupied by the field. (This is the well-known theorem of classical potential theory, frequently called the "Thomson principle"). Therefore, the magnetic field of an active region in a preflare state cannot be a potential field, that is, a current-free state. In other words, above the surface of the photosphere in a preflare state there should be a current which changes its configuration or intensity in such a way that the energy of interaction

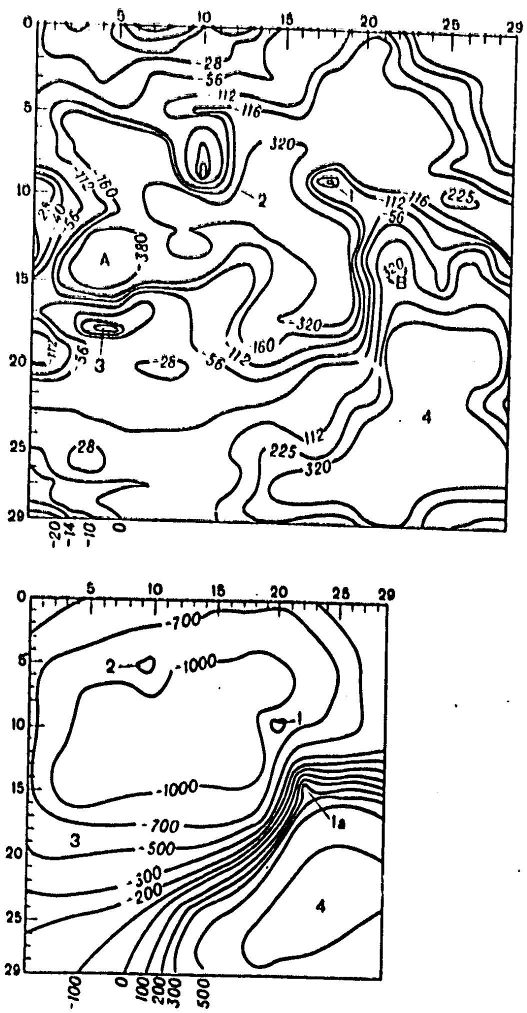
Note: Cases of flares in active regions in the absence of spots are known (see SOLAR PHYSICS, Vol 36, pp 403-416, 1974.

of the current with the external field together with the characteristic energy of the current field is less than the sum of the corresponding initial values. The difference is the flare energy. Accordingly, from the fact that the flare energy is drawn from the magnetic energy of an active region it can be concluded that there is an electric current in the sun's upper atmosphere and that it plays the role of an intermediary in the transformation of energy.

Finally, an evaluation of current intensity (lower evaluation) has the same basis and therefore must be assigned to this same type of reliable theoretical principles. This value is not less than 10^{12} A (S. I. Syrovatskiy, 1976) when the flare energy is about 10^{32} erg.

Changes in structure of active region in H_α before proton flare of 7 September 1973 (V. I. Makarov, M. M. Molodenskiy, 1975). a) quiet filament two hours before flare, b) filament before onset of explosive phase of flare acquires the configuration of a twisted cord: this is evidence of a change in the current over the photosphere, and in particular, an increase in the current flowing along the filament.

With respect to the upper evaluation for current intensity, here the theoretical principles for the time being can be classified as probable or possible. The most important of these principles is that the field of an active region in general differs little from a potential (harmonic) field. A comparison of the energy of flares with the total energy of the magnetic field of the active region shows that the energy of the magnetic field exceeds the energy of flares by two or three orders of magnitude. Therefore, a current of about 10^{12} A exerts no considerable influencé on the general field geometry. A considerably greater current could appreciably distort the potential field, but such a current, speaking in general, should lead to phenomena two or three orders of magnitude more powerful (which never has been observed). What has been said, obviously, gives only an indirect basis for considering the current to be relatively weak and the field to differ little from a potential field.



Longitudinal magnetic field (at top) and potential (at bottom) of active region McMath 11693 on 18 February 1972. A flare of importance 2 occurred in this active region. A, B -- large spots with different polarity, 1, 2 -- singular points in field; in regions 1a, 3 and 4 there are the necessary but not the adequate conditions for existence of singular points; region 3 (upper figure) is a spot satellite. A is a field "impregnation" with a sign opposite that in the surrounding field; potential extrema exist in regions 1a and 4 -- these regions do not create singular points.

In solving the problem of the nature of the field in the chromosphere and corona it is best to use a direct approach in measuring the magnetic field in the photosphere with subsequent computation of circulation of the field vector in some closed contour. This approach affords a fundamental possibility for finding the intensity of the current normal to the photosphere (A. B. Severnyy, 1971). However, errors in measuring the field using magnetographs of the Babcock type considerably complicate interpretation of such data. Accordingly, the need arose for developing a magnetograph making it possible to carry out measurements of the tangential field with a higher accuracy than was possible before. Such a magnetograph has now been created at the Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation USSR Academy of Sciences (G. M. Nikol'skiy, et al.). There are also additional indications that the presence of a current disturbs the potential field relatively little. First of all, as a result of comparison of the form of the magnetic surfaces of the potential field with the isophots of the coronal condensations there was found to be a correspondence of their forms. Second, a comparison of the directions of the potential field lines of force with the direction of the filaments also indicates a small difference between these fields and potential fields. Third, it follows from general magnetohydrodynamic theory (from the energy principle) that the longitudinal current always serves as a nonstabilizing factor; therefore, stability has been demonstrated only for fields in the sun's upper atmosphere differing little from potential fields.

An extremely important problem is the localization and configuration of the current. This problem for the time being can be solved on the basis of the preceding, probable theory of field quasipotentiality. On its basis it is possible to formulate a geometrical (and topological) theory of magnetic fields of active regions. Up to the present time this problem has been examined at the level of models: the field has been represented by some number of dipoles or individual spots situated in the photosphere. At the same time, the field of active regions is an example of an extremely complexly structured vector field (and an extremely detailed measured field); Therefore, model representations do not make it possible to use the greater part of the field information.

The expansion of the field in spherical harmonics used in classical problems (description of the magnetic and gravitational fields of the earth and planets) in this case is ineffective. Therefore it is necessary to turn to the general theory of vector fields making it possible to describe the qualitative structure of the field (in the sense of its topological properties), and also to draw basic conclusions concerning the number and positioning of singular points in the field. It must be noted that the use of numerical methods in solution of the boundary problem arising here (Neumann problem) is completely necessary, but at the same time it is extremely important to have preliminary information on the singular points which can be obtained from an analysis of the boundary conditions.

The general idea of a qualitative description of vector fields was expressed about a hundred years ago by A. Poincaré. This idea is based on the following analogy. In order to describe the behavior of a scalar function of one argument it is sufficient to mention the positions and types of extremal points (maxima, minima and inflection points) and also the asymptotic behavior of the function when $x \to \pm\infty$. Using continuity, it is possible to form a more general idea concerning the behavior of this function. In the case of a vector field the situation is similar, and the role of extrema is played by the singular points in the vector field. The asymptotic behavior is also known for the magnetic fields: except for cases of special symmetry, the field usually tends to a dipole field with $|r| \to \infty$. Therefore, in order to form some idea concerning the field structure it is necessary to indicate the number, type and position of the singular points. With respect to their position, to a considerable degree this is a problem in quantitative analysis and it is solved on the basis of computations. The type of singular points in a potential approximation is known for the magnetic field; these are always saddle points (with a positive or negative index). Finally, the sum of the indices of the singular points can be obtained by means of an analysis of the boundary conditions, and specifically by calculation of the characteristic known as vector field rotation (VFR). Thus, the theory of indices of vector fields makes it possible to introduce a completely rigorous classification of the fields of active regions by means of use of a new, physically meaningful parameter determining the "degree of field complexity."

The traditional "Zurich" classification of spot groups is customary and simple, but it does not reflect the real topological field complexity. The introduction and broad use of magnetic field rotation (MFR), and also use of the absolute magnetic field (AMF) value instead of spot areas, is extremely modern and promising. We note that in a three-dimensional case the index of field rotation, determined as the "degree of representation" of the field on a unit sphere of directions, is not equal to the number of singular points above the photosphere, but is only the difference in the number of positive and negative indices of the singular points. However, it is obvious that generally speaking there is a correlation between the difference and the total number, and since the flares are related to field complexity, MFR can serve as a characteristic of the flare activity of groups. Thus, in addition to the absolute magnitude of the flux, in essence, the energy characteristic of the field, it is also possible to mention another characteristic reflecting the degree of field complexity.

Thus, on the basis of a probabilistic principle of the theory (that concerning potentiality) it is possible to indicate the positioning of singular points and find the general field structure. In a case when it is possible to discriminate systems of independent magnetic fluxes, a current arises on the "limiting" line of force separating these fluxes. A correlation was established between the parameters of plasma in the neighborhood of this line and the characteristics of the current layer (S. I. Syrovatskiy, 1976).

In particular, for powerful flares with an energy release of about 10^{32} erg on the basis of theory it was possible to obtain the characteristic time of formation of the current layer ($3 \cdot 10^4$ c $\approx$ 10 hours) and a stationary intensity $\approx 8 \cdot 10^{27}$ erg/sec, being released for the most part in the region of the far ultraviolet. These characteristics must evidently be regarded as possible. For the time being there are no direct experimental data on the genesis of the current layer before a powerful (about 10^{32} erg) flare. Therefore, it is extremely important to carry out systematic observations of the intensity of solar UV radiation and its variations during a period of increased activity. Measurements carried out before flares and during the period of their development are of special interest. In addition to direct measurements which can be carried out from artificial earth satellites it is of great importance to make observations of sudden ionospheric disturbances causing a Doppler frequency shift of radio signals reflected from the ionosphere (SFD -- Sudden Frequency Deviations), and also regular observations of the state of the ozone layer, being a sensitive indicator of UV radiation.

If the preliminary theoretical considerations on the mechanism of the genesis and development of flare processes find confirmation in the characteristics of the observed UV or radiofrequency radiation before a flare it becomes possible to make a reliable short-range prediction of a flare. This problem can be solved successfully on the basis of regular high-quality measurements of the magnetic fields of active regions on the sun, obtaining information on the structure of the chromosphere and corona in optical lines, and systematic monitoring of radio emission in combination with regular monitoring of solar UV radiation by direct and indirect observations (observations of SFD, monitoring of the ozonosphere, etc.).

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II. OCEANOGRAPHY

Translations

ACTIVITY OF THE INSTITUTE OF OCEANOLOGY IMENI P. P. SHIRSHOV

Moscow VESTNIK AKADEMII NAUK SSSR in Russian No 5, 1979 pp 3-8

[Unsigned article]

[Text] The Institute of Oceanology imeni P. P. Shirshov, established in 1946, is engaged in a complex study of physical, chemical, geological and biological processes in the world ocean, and also the development of means and methods for investigating it. The institute has an Atlantic Division in Kaliningrad, a Southern Division at Gelendzhik and a Section of Mathematical Modeling of Circulation of the Ocean and the Atmosphere at Leningrad. An experimental design bureau operates at the institute. The institute has the scientific research ships "Vityaz'," "Akademik Kurchatov," "Dmitriy Mendeleyev," and also seven small vessels.

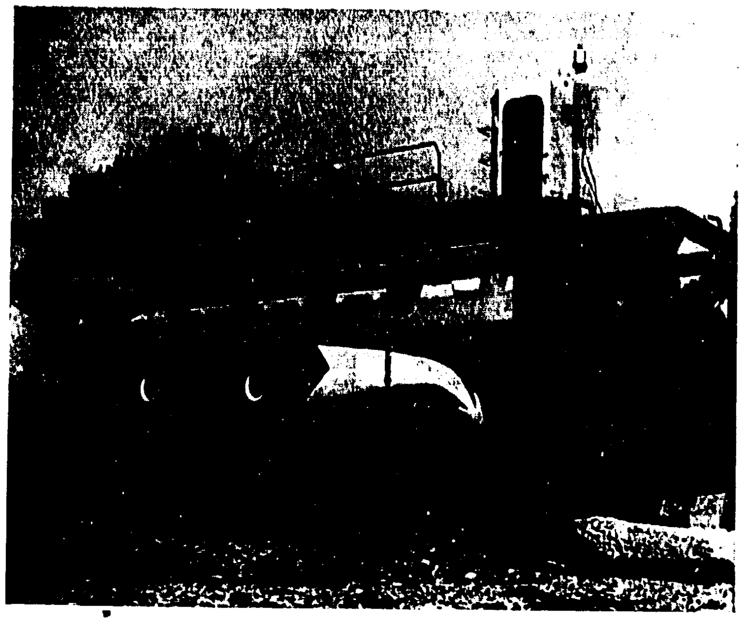
The Presidium of the USSR Academy of Sciences discussed the activity of the Institute of Oceanology imeni P. P. Shirshov. A report was presented by the institute director, A. S. Monin, Corresponding Member USSR Academy of Sciences.

Report of A. S. Monin

The scientific activity of the institute, stated the speaker, is directed to the solution of highly important problems in oceanology as a unified, complex science, and also practical problems of great importance to the national economy. Theoretical and experimental investigations are being made on the basis of modern attainments in physics, hydromechanics, applied mathematics, geology, chemistry and biology.

Physics of the ocean occupies a key place in the institute's work. One of the principal events in oceanology during the last 10 years was the discovery, by the institute's expeditions, of mesoscale eddies having a diameter of several hundred kilometers and penetrating many hundreds of meters into the depth of the ocean. Most of the energy of ocean currents is concentrated in these eddies.

The discovery of these eddies has forced a re-examination of concepts concerning the field of ocean currents and the task now is learn to predict the detailed structure of currents in the ocean with the influence of eddies taken into account.



The "Chernomor" sealab ensures multiday work of a crew of 4-5 men at depths up to 30 m.

At the institute there has been considerable development of numerical modeling of global currents and tides. Studies have been made of nonstationary and long-period movements in the ocean, including effects associated with different mechanisms of wave excitation, variable ocean depth, the earth's influence, and also taking into account viscosity and resonance phenomena. These studies are being carried out in close collaboration with the institutes of the Siberian Division USSR Academy of Sciences.

The geophysical probes with an increased resolution created at the institute made it possible to detect a well-developed vertical microstructure of the ocean. [See: K. N. Fedorov, "Fine Structure of Physical Fields in the Ocean," VESTNIK AN SSSR, No 2, 1978.] Extensive experimental studies have been made of internal gravitational waves. The possibility of generation of a fine structure of hydrophysical fields in the ocean during the passage of internal waves has been demonstrated.

Investigations of ocean microstructure are closely associated with a study of its small-scale turbulence. The large-scale measurements of the small-scale component of ocean turbulence which have been carried out have led to new concepts concerning it as being weak turbulence (with small Reynolds numbers), concentrated in thin extensive microstructure layers.

"Krolik" on-shore hyperbaric complex. It is used in carrying out tests of apparatus and for medical-physiological investigations with the prolonged presence of people in artificial atmospheres at pressures up to 35 atm.

Interesting results were obtcined in the field of ocean optics.

A global numerical model of interaction between the ocean and the atmosphere has been developed. It makes use of new methods for the parameterization of small-scale interaction. As demonstrated by numerical experiments, the model is suitable for the modeling of climate.

Broad investigations of interaction between the ocean and the atmosphere were carried out during the experiments "Tropeks-72" and "Tropeks-74."

Studies have been carried out for investigating the distribution of macrocomponents and microcomponents of gases, organic matter, the processes of their variability, annual circulation and balance in the waters of the world ocean. Specially synthesized polymer sorbents have been proposed and tested. These are for the extraction of uranium, silver and other trace elements from sea water.

Institute scientists have investigated petroleum contamination of waters in the world ocean. Dispersing substances have been developed for eliminating the petroleum film forming when petroleum pours out on the sea.

The institute carries out extensive work in the field of geology of the ocean. The principles of marine geology have been formulated. Methods for geological-geophysical investigations of the floor of deep parts of the ocean have been developed and are in extensive use. Studies have been made of the quantitative and qualitative regularities and patterns of present-day sedimentation, the distribution and composition of sedimentary and igneous rocks on the ocean floor. Extensive regions of metalliferous sediments have been discovered.

The distribution of ferromanganese nodules, rare and disperse elements, has been investigated in the Pacific and Atlantic Oceans.

Promising petroleum and gas regions have been discovered on the shelves and floors of the Baltic Sea and the Sea of Okhotsk. New data have been obtained on the relief of the crystalline basement and the structure of the sedimentary layer under the floor of the central Caspian. Recommendations have been made for carrying out reconnaissance and prospecting work for petroleum and gas.

Concepts have been developed concerning the generation of movement of lithospheric plates by deep processes. Models of processes of thrusting of lithospheric plates under island arcs and the active margins of continents have been formulated. Studies have been carried out on the paleogeography of the Phanerozoic. Maps of movement of the continents during this period were prepared.

As a result of the investigations carried out by the biological subdivisions of the institute it was possible to ascertain the basic patterns of distribution of biological objects in the ocean, the peculiarities of zones with high and low productivity, vertical faunistic zonality, and maximum depths of abyssal trenches in the ocean. There has been development of work in a new direction for the institute: study of functioning of ocean biosystems and the creation of biological productivity in them. New methods have been proposed for investigating biological groups (bacteria, protozoa, microzooplankton). Diagrams of the cycling of matter and the absorption of energy in biological systems in pelagic regions of the ocean have been prepared. Specialists have formulated mathematical models of the functioning of biological communities in pelagic regions. On the basis of these models it has become possible to predict the development of such communities.

The results of these investigations constitute an important step in solution of the fundamental practical problem of a changeover from the operation of fisheries to the rational cultivation and collection of the biological production of the ocean.

Oceanological instruments have been created at the institute. Operating models of a seismoprofilograph and side-scan sonar have been fabricated and using them it has been possible to obtain seismic profiles in the oceans over a distance of 100,000 miles. Towed instrumentation has been developed and used under expeditionary conditions for measuring turbulence, as well as hydrophysical probes, digital current meters, hydrooptical instruments and a number of models of instrumentation for geological and biological investigations.

The institute successfully completed a series of studies in the "Chernomor" sealab. Conclusions were drawn concerning the limiting depths of long-term presence of aquanauts in a nitrogen-oxygen atmosphere. The "Krolik" hyperbaric chamber was created. It affords a possibility for carrying out experiments for study of the effects of pressures up to 35 atm on the human body. The "Krab" television manipulator has been developed and is being used (its depth of submergence is up to 1.5 km). The "Argus" underwater apparatus has been constructed (submergence depth to 600 m). Investigations are being carried out using the "Paysis" underwater vehicles at depths as great as 2 km. In 1977 these vehicles were used in carrying out a successful complex geological-geophysical investigation of the floor of Lake Baykal, making it possible to obtain important scientific results. [See: Ye. G. Mirlin, A. M. Podrazhanskiy and A. M. Sagalevich, "Geological-Geophysical and Underwater Investigations on Baykal," VESTNIK AN SSSR, No 11, 1978.]

The institute is carrying out a great volume of practical investigations. It has formulated scientific recommendations on contending with worldwide contamination of waters in the seas and oceans, on the development of fisheries, and improvement of navigation. These recommendations are being used successfully in the national economy.

The work of the Institute of Oceanology is being carried out in close collaboration with other institutes of the USSR Academy of Sciences, ministries and departments. The institute also has close bonds with foreign oceanological organizations and is taking an active part in carrying out investigations.

In conclusion, the speaker told about the difficulties which the institute encounters in its activity. The equipment and production base of the institute is inadequate for carrying out important and responsible tasks assigned it. The experimental-design bureau for oceanological apparatus does not fully ensure the institute with instruments and equipment for field and laboratory experiments. The technical facilities available to the institute are not always used effectively enough.

After the report a communication was presented by Academician Ye. P. Velikhov, a commission member of the USSR Academy of Sciences Presidium familiar with the institute's activity. In the opinion of the commission, stated Ye. P. Velikhov, the Institute of Oceanology is a major scientific center in the field of ocean studies. The most important attainment of the institute is that it has succeeded in bringing together different aspects of ocean research -- its physics, hydrodynamics, biology, bottom geology. Interaction with the institutes of the USSR Academy of Sciences has been well established.

Then Ye. P. Velikhov presented commission recommendations related to the difficulties which the institute is experiencing in its work. In particular, the commission recommended a strengthening of the computation base of the institute. Since the institute is carrying out extensive experimental investigations in sea polygons and abyssal investigations, it is also necessary to strengthen its production base, ensure supply with instruments and equipment.

Discussion of Report

Academician A. L. Yanshin. The Institute of Oceanology over the course of the last 10 years has been producing first-class scientific publications An example is the multivolume work TIKHIY OKEAN (Pacific Ocean), which has been awarded the USSR State Prize (1977). Many of the published works of the institute are being translated into foreign languages, evidence of their high international authority.

A great merit of the institute's work is the close relationships with academic institutions and the institutes of other departments and also its broad international connections.

Now ever-increasing attention is being devoted to the exploitation of the mineral resources lying on the floor of the Pacific Ocean (even today 24% of all petroleum is produced from the floors of the seas and oceans). Evidently, the Institute of Oceanology must intensify research in this direction in order to play a key role not only in the study of sedimentation, but also the resources lying on the floors of the seas and oceans.

Academician V. Ye. Sokolov. The biological studies of the Institute of Oceanology are quite well known. The commission of the USSR Academy of Sciences Presidium working at the institute (V. Ye. Sokolov was a commission member and was acquainted with the activity of the biological laboratories) raised the question as to whether it was legitimate for biological laboratories to be a part of the Institute of Oceanology. The joining together of physicists, chemists, geologists and biologists in a single institute is desirable when they carry out smooth complex work in a single direction. The commission drew the conclusion that at the Institute of Oceanology there is such a direction -- study of ecosystems in the ocean and its productivity. However, at the institute it is necessary to reduce classical biological investigations to a minimum and against this background establish closer contact with the Division of General Biology.

Admiral-Engineer P. G. Kotov. The scientific problems which are being solved by the Institute of Oceanology in collaboration with other institutes of the USSR Academy of Sciences are of great practical importance. It is necessary to devote much attention to study of the hydrophysical and hydroacoustic characteristics of individual regions of the ocean for determining general conditions in the ocean. There is still much that is unknown in the ocean. For example, this is true of the eddies, for which additional profound investigations are necessary. It is necessary to accelerate the development of a complex program of field studies, including hydrophysical and hydrological investigations.

It is desirable that there be further development of the professional contacts between the Institute of Oceanology and institutes of other departments using the results of fundamental investigations for creating practical engineering apparatus.

Academician L. M. Brekhovskikh. The board of the Division of Oceanology, Physics of the Atmosphere and Geography, in discussing the work of the Institute of Oceanology, noted its great successes in study of physics, biology, geology and chemistry of the ocean, the great productivity of the multisided approach to study of the ocean, the need for further development and application of this approach.

The Institute of Oceanology, despite having inadequate technical equipment, is functioning at the level of the leading scientific oceanological institutes of the world. Its successes are attributable both to the successful selection of personnel and the productive combination of theoretical and experimental investigations.

A major undertaking of the institute has been compilation of the 10-volume monograph OKEANOLOGIYA (Oceanology), which affords a full idea concerning the status of the entire science of the ocean. Four volumes of this monograph have already been published.

The board of the division assumes that the institute should be more concerned with model laboratory investigations and must carry out more intensive work in sealabs.

Academician A. Yu. Ishlinskiy. Study of the ocean is a broad field of applications for investigations in the field of mechanics. The motion of water is closely related to the movement of air masses and here there must be specific hydrodynamic and aerodynamic investigations. Close contacts have been established between the Institute of Oceanology and the Institute of Mechanical Problems and a number of problems in hydrodynamics and acoustics are being solved jointly. In the implementation of such investigations under laboratory conditions the Institute of Mechanical Problems can assist the Institute of Oceanology, since it has great experience in constructing the necessary apparatus.

Academician A. V. Sidorenko. The Institute of Oceanology is carrying out much important work on a broad complex of problems related to the mastery of the world ocean. There is a need for strengthening the material-technical base of the institute, but the available equipment and methods are not being used sufficiently effectively.

The institute should occupy an active position in study of the shelves. Since multisided investigations are being carried out at the institute relating to the physics and chemistry of the water medium, biosphere and geology it is necessary that there be clear, well-organized coordination of this work.

The results of the discussion were summarized by Academician V. A. Kotel'nikov, Vice President of the USSR Academy of Sciences.

Decree

The Presidium of the USSR Academy of Sciences approved the scientific and scientific-organizational activity of the Institute of Oceanology imeni P. P. Shirshov USSR Academy of Sciences.

The principal directions in the scientific activity of the institute include the development of theoretical problems in oceanology, the carrying out of investigations of the oceans and seas on the basis of the concept of the unity of the physical, chemical, biological and geological processes transpiring in the seas and oceans.

The efforts of the institute must be concentrated on solution of the following problems: hydrology of the world ocean; physical fields in the world ocean; interaction between the ocean and the atmosphere; chemical processes of transformation of substances in the ocean; geological principles for the exploitation of the mineral resources of the world ocean; geotectonics of oceanic regions of the earth; control of biological productivity of the ocean; research equipment and experimental methods; underwater research.

[416]

PREDICTION OF WATER TEMPERATURE IN THE OCEAN

Leningrad PROGNOZ TEMPERATURY VODY V OKEANE (Prediction of Water Temperature in the Ocean) in Russian 1979 signed to press 27 Nov 78 pp 3, 4-5, 6-8, 167-168

[Editor's note, foreword, introduction and table of contents from book by M. G. Glagoleva and L. I. Skriptunova, Gidrometeoizdat, 1,200 copies, 168 pages]

[Text] Editor's Note. The prediction of individual phenomena or elements of the sea's regime requires a knowledge of the processes transpiring in the ocean and atmosphere, their interaction and interrelationship. That is why the level of development of marine hydrological predictions is dependent to a considerable degree on our knowledge in the field of large-scale circulation of the atmosphere and successful solution of the problem of weather forecasting for any particular time in advance.

A role of more than a little importance, if not the basic role in the development of marine forecasts is played by the availability of data from hydrometeorological observations from the entire surface of the seas and oceans which are of a sufficient degree of accuracy and spatial-temporal discreteness. The lack of such data is a serious impediment in the study of physical and other processes transpiring in the waters of the world ocean, and accordingly, in the field of development of methods for making sea hydrological predictions. Despite the mentioned difficulties, investigations in the field of marine hydrological forecasts are successfully developing. Generalizations of theoretical and empirical studies based on an analysis of the physical processes transpiring in the ocean and making it possible to comprehend the essence of the considered phenomenon will make it possible to evaluate the level of present-day investigations in the field of marine forecasts and discern ways to develop them further, including methods for computing and predicting the thermal structure of the active layer in the ocean. It is this theme to which this monograph is devoted.

This monograph is the first attempt at generalization of Soviet and foreign studies on predictions of water temperature in the ocean. It not only sets forth individual physicostatistical and hydrodynamic studies on computations and predictions of water temperature and depth of the thermocline, but also gives evaluations of these from the point of view of the professional forecaster.

Without question, this book will be of interest not only for professional oceanologists, but also for specialists in other branches.

A. I. Karakash

Foreword. Predictions of the thermal state of the ocean warrant the closest attention from investigators of the ocean and atmosphere. The success of many types of human activity (fishing, merchant marine operations, etc.) is dependent on the reliability of water temperature forecasts.

In the problem of interaction between the ocean and the atmosphere an important place is occupied by the problem of formation of the temperature field in the ocean and prediction of its changes.

The basis for the development of forecasts of the thermal state of the seas and oceans was the fundamental investigations of the Soviet scientists Yu. M. Shokal'skiy, V. Yu. Vize, N. N. Zubov, V. V. Shuleykin, A. D. Dobrovol'skiy, A. I. Duvanin, V. V. Timonov, V. B. Shtokman, N. A. Belinskiy, A. I. Karakash, K. I. Kudryavaya, Yu. P. Doronin and others.

During the last 15-20 years it is possible to note progress in investigations of the thermal regime of the sea. In particular, at the USSR Hydrometeorological Center great attention is being devoted to study of the thermal regime of the sea, and as a result, methods have been developed for short-range, long-range and superlong-range predictions of water temperature. Whereas the first studies related to individual points or limited regions of the seas, later conditions were created for the development of methods for predicting the distribution of water temperature over the entire water area of the northern parts of the Atlantic and Pacific Oceans. The considerable short-term variability of temperature discovered by means of multiday stations makes it necessary to re-evaluate the importance of short-range forecasts.

The methods for predicting water temperature have been set forth in articles published in scientific journals, transactions of institutes, conferences, etc. There have been very few generalizations of these topics. Among the foreign writings we should mention the book by Laevastu and Hela on commercial oceanography [item 77 in the list of references] in which considerable attention is devoted to predictions of water temperature and a book by James on prediction of the thermal structure of the ocean [item 39 in the list of references].

A generalization of Soviet studies of water temperature prediction can be found only in corresponding relatively small sections of textbooks on marine forecasts and in a preliminary bulletin with a review of short-range forecasting methods [item 36 in the list of references].

The objective of this monograph is a review of Soviet and foreign studies which set forth the methods for predicting water temperature, and to a lesser degree relate to diagnostic schemes.

The authors express appreciation to A. I. Karakash for valuable advice received during the writing of this monograph and express sincere appreciation to Ye. G. Nikiforov for useful comments made during review of the manuscript.

The section "Short-Range Forecasts" was written by L. I. Skriptunova and the section "Long-Range Forecasts" was written by M. G. Glagoleva.

Introduction. Fundamental investigations in the field of oceanology in our country and abroad have been directed to the creation of a physicomathematical basis in the field of marine forecasts. The improvement of computation methods is favoring the solution of complex mathematical problems on an electronic computer. But at the present time the use of hydrodynamic models in predicting the characteristics of the ocean regime is still limited. An obstacle to this is the complexity of the processes transpiring in the ocean and the shortage of hydrometeorological information. It is impossible to describe the processes transpiring in the oceans and seas by linear equations and the introduction of nonlinear terms creates mathematical difficulties. In theoretical models it is very difficult to make allowance for the influence of local conditions on the characteristics to be predicted and to introduce a great number of determining arguments. The uncertainty of many parameters entering into the equations of hydro- and thermodynamics, such as the coefficients of turbulent mixing, the roughness parameter and others, introduces additional difficulties when using theoretical models for practical computations.

At the present level, the basic methods employed in routine work are physicostatistical methods.

It must be remembered that there is a correlation between the two methods. Applicable to weather forecasts, N. A. Bagrov wrote: "The framework of the physical model must rest on some generalization of known empirical factors and all the numerous parameters of the model also, as a rule, are set by the empirical-statistical method... In the second approach to the forecasting problem requirements on the physical structure of the atmosphere must be imposed on the stochastic model, although in the most general form" [9]. These considerations unquestionably also apply to marine forecasts.

The development of the theory of random functions, the development of practical procedures for the statistical analysis of observational data and the accumulation of field data favored the development of physicostatistical methods. It is now possible to precompute many characteristics of the sea and ocean regime.

James [39] has written about the empirical nature of prediction of thermal structure. Laevastu and Hela [77] also note that the practical use of commercial oceanography involves a correlation analysis of different data.

Most prediction methods, both hydrodynamic and statistical, are based on an allowance for the influence of meteorological processes on hydrological processes. It is known that the ocean in turn exerts an influence on atmospheric processes. Therefore, studies in which the influence of the atmosphere and hydrosphere on one another are taken into account appear promising. The joint solution of equations for the atmosphere and hydrosphere makes possible simultaneous computation of characteristics of both the atmosphere and ocean. In marine predictions a special place is occupied by methods based on an allowance for external factors: cosmic and geophysical. Such factors include solar activity, variations of the earth's axis of rotation, the long-period lunar tide, etc. The discovered cycles in variations of these external factors and in the course of individual hydrometeorological elements and phenomena made it possible to obtain methods for making forecasts a long time in advance.

During the entire period of development of sea predictions the role of meteorological forecasting has been raised and discussed. At first glance it appears obvious that sea forecasts must be based on weather forecasts. But difficulties arise in their practical application. When using long-range weather forecasts, due to their low probable success, the success of marine forecasts is greatly reduced. In short-range forecasts there are great possibilities for the use of meteorological forecasts, but these possibilities are limited. For example, forecasts of many meteorological elements are not prepared for the open regions of the seas and oceans (air humidity, cloud cover, etc.). Therefore in developing short- and especially long-range predictions an effort is made to not use weather forecasts. In nature there is a lag in changes in hydrological elements in comparison with meteorological elements (for example, sea level in comparison with the wind, water temperature in comparison with air temperature, etc.); this lag is used in setting the advance time of the forecasts. Since these time intervals are not always sufficiently great, it is necessary to use short-range meteorological forecasts (wind, air temperature forecasts) for increasing the advance time of the forecast. In developing methods for long-range hydrological predictions without using a meteorological forecast a weather forecast is prepared indirectly. For example, in preparing a prediction of ice conditions on the basis of the preceding pressure situation in actuality an air temperature forecast is prepared.

An important role in the development of methods for predicting hydrological elements for open regions of the seas and oceans has been played by long-term observations at multiday stations in the oceans and seas, work which began in the late 1950's. The so-called synchronous surveys, in actuality stretched out over rather long time intervals, did not make it possible to separate temporal and spatial changes in hydrological elements. Therefore, only the setting out of buoy stations with automatic current recorders and prolonged observations of water temperature and meteorological elements at these points in the ocean made it possible to develop methods for predicting thermal structure and sea currents.

Several directions in methods for predicting water temperature have now taken form. The authors of this monograph have striven, insofar as possible, to examine studies made in the principal directions.

Part I deals with methods for short-range predictions of water temperature, whose advance period is from several hours to several days; Part II is devoted to methods for long-range predictions for a month or more in advance.

Approaches to the development of prediction methods with different advance periods have their peculiarities and they will be pointed out in the exposition of specific methods.

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III. TERRESTRIAL GEOPHYSICS

Translations

USE OF GRAVIMETRIC PROSPECTING FOR DETECTION OF SALT OVERHANGS ON DOMES IN THE CASPIAN DEPRESSION

Moscow RAZVEDOCHNAYA GEOFIZIKA in Russian No 83, 1978 pp 65-71

[Article by A. V. Matusevich]

[Text] The prospects for finding petroleum and gas in the Caspian depression are associated to a considerable degree with the above-salt Pre-Jurassic complex of deposits, whose structure is complicated by intensive manifestation of salt tectonics. In this layer there can be deposits of petroleum and gas screened by steep salt slopes. The most favorable conditions for the formation of such traps are created when the salt plugs are complicated by overhangs ("cornices"). The existence of the latter was confirmed by deep drilling in some domes of the interfluve between the Ural and the Volga, in the Emba region and in the eastern marginal part of the Caspian depression. A petroleum gusher (borehole G-31) was obtained from Triassic deposits beneath an overhang on the Zhanatalap salt dome structure. Taking the above into account, the mapping of salt overhangs is acquiring great importance in petroleum prospecting.

Not only a detailed study, but also the detection of salt overhangs, is still an extremely complex problem. Using seismic prospecting by the reflected and refracted waves methods it is possible to trace the top of the salt only in the arched parts of the domes. Reflections from the steep slopes and especially from the lower surface of a salt overhang are discriminated extremely rarely and inadequately reliably even when using such complex modifications of seismic prospecting as the controlled refracted waves method, directional profiling method, common deep-point method. This served as a basis for investigating the problem of the possibility of using data from gravimetric prospecting for the prediction of salt overhangs.

It is known that the salt domes in the Caspian depression are manifested in the gravitational field by strong minima. For this reason detailed gravimetric surveys are being made on a large scale at the present time and this is affording broad possibilities for use of the gravitational field in solving more complex geological problems: study of steep salt slopes, the depth of salt in the zones between domes, the tracing of dislocations in the thickness of deposits above the salt, etc.

The gravitational minima over salt domes are caused by reduced density of the layer relative to the overlaying rocks of the complex of deposits above the salt. The Kungurskaya salt of the Caspian depression has a density close to 2.2 g/cm^3. The density of the deposits over the salt near the surface is approximately equal to the density of the salt, and sometimes is even somewhat less than it. With increasing depth the density of rocks in the complex above the salt increases, attaining 2.6-2.7 g/cm^3.

Such a degree of increased density of the deposits above the salt is observed at different depths in different regions of the Caspian depression. In the eastern marginal part of the depression -- at a depth of about 3 km, in the center of the region (Aralsorskaya superdeep borehole) -- 6 km, and in the Emba region -- about 5 km. The development of salt tectonics led to considerable differences in depths to the top of the salt: from 0 to 5 km or more. Accordingly, the density jump at the boundary between the deposits above the salt and the salt varies from values close to zero to 0.4-0.5 g/cm^3.

In the interpretation of the gravitational field of the Caspian depression the excess density of the deposits above the salt is regarded as a function of depth. For the Emba region the following dependence was proposed by L. Ya. Tushkanov: $\sigma = 0.1 \cdot H + 22$ when $H \leqslant 5$ km; $\sigma = 2.7$ when $H > 5$ km (σ is density in g/cm^3; H is depth in kilometers). [L. Ya. Tushkanov, "Interpretation of Gravity Anomalies for Bodies of Variable Density," PRIKLADNAYA GEOFIZIKA, No 30, Moscow, Gostoptekhizdat, pp 154-162, 1961.] We used this dependence in modeling for the purpose of studying the presence of salt domes and overhangs complicating their slopes in the gravitational field.

Computation of the gravitational field from the investigated models of salt domes was accomplished using a "Minsk-32" electronic computer prepared specially for the conditions of the Caspian depression. The gravitational effect was computed from the deposits above the salt, approximated by rectangular parallelpipeds whose measurements along the direction of the profile increase from 0.25 to 2.5 km with increasing distance from the computed point. The gravitational influence of masses at a distance as great as 22.5 km was taken into account. The program provided for a jump-like density change in a vertical direction.

In solving the direct problem it is possible to approximate the model by parallelpipeds whose dimensions are not the same in different sectors along the strike. The program makes it possible to compute the gravitational effect from models of salt domes complicated by overhangs. The direct problem is solved quite quickly. If the model consists of a set of parallelpipeds with identical dimensions along the strike the gravitational effect at a hundred points is computed in 10 seconds.

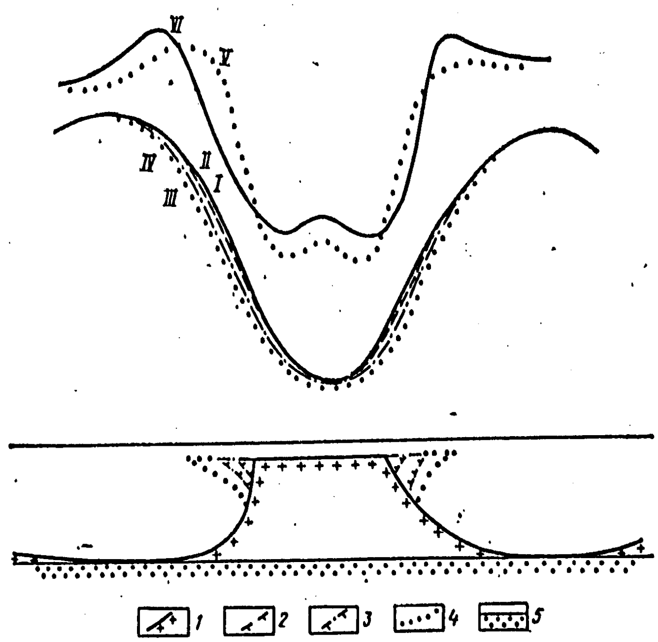

Fig. 1. Models of gravimetric profiles over salt domes. 1) top of salt in main model; 2-4) different variants of overhangs complicating salt mass; 5) subsalt horizon; I-IV) curves of gravity anomalies $\delta\Delta g$ corresponding to models of salt domes 1-4; V, VI) Δg curves transformed by the Andreyev-Griffin method corresponding to salt domes 1 and 4.

The program provides for solution of both the direct and inverse problems in gravimetric prospecting. In solving the latter the section is approximated by parallelpipeds of identical dimensions along the strike. The selected model is described at each point on the profile by one parameter -- depth to the top of the salt. In such a variant it is impossible to examine a section with salt overhangs because for determining the latter it is necessary to stipulate three values of depths at a point. The change in depths in each cycle of approximations is accomplished automatically on the basis of the difference in the values of the interpreted and computed anomalies with use of correlation of anomalies and depths. For a satisfactory selection of a model it is usually necessary to use 7-12 successive approximations. For a profile 100 km in length a total of 3-5 minutes computer time is required.

The program provides for the imposing of limitations on the change in depths to the top of the salt when selecting the model. The restrictions can be rigid (the depth to the salt in the selection process does not change at fixed points) and of the "interval" type (depth to the salt varies in a stipulated interval). "Rigid" depths are used at points where the top of the salt has been penetrated by boreholes or reliable reflections have been received from it. In the "interval" restriction of depths the maximum value used is the depth to the subsalt deposits, and the minimum value used is the depth to the deepest of the horizons above the salt traced by seismic prospecting.

We computed anomaly curves from models of salt domes without overhangs and with overhangs of different sizes (Fig. 1). The dimension of the domes along the strike was assumed to be equal to 24 km, whereas the extent of the overhangs in this direction was assumed to be 8 km. In the computations we took into account the gravitational influence of adjacent domes intersected by the profile. The computations indicated that the gravitational effect created directly by the salt overhangs is relatively small. From an overhang with a width of 1 km the intensity of the anomaly is 0.5 mgal, and with an increase in its width to 3 km the anomaly attains from -2.0 to -2.5 mgal. Modern gravimeters make it possible to measure the gravitational field with an accuracy ensuring reliable registry of anomalies of such an intensity. However, the gravity minima caused by the overhangs are situated under conditions extremely unfavorable for their discrimination. In these sectors there are considerable gradients of the anomalous field created by salt masses. The intensity of the gravitational minimum from the models of salt bodies which we have considered exceeds 20 mgal. The amplitudes of the anomalies over salt dome structures in the Caspian depression frequently exceed this value.

Attempts at separating the anomalies from the salt overhangs and from the main mass of the salt bodies by means of filtering of the total field were unsuccessful. We tested different types of transformations with different grid radii. For example, the radius of the grid when carrying out field transformation by the Andreyev-Griffin method varied from 1 to 4 km. Figure 1 shows anomalies from domes with and without overhangs, transformed by the Andreyev-Griffin method with a radius of 2 km. These curves do not differ qualitatively.

Using anomaly curves computed from models of salt domes complicated by overhangs we solved inverse problems on a "Minsk-32" computer using the program described above. It was found that if the depths to the top of the salt are considered known only in the middle part of the dome arch (outside the overhang sectors) a form of the top of the salt is selected whose relief is not complicated by overhangs and the gravitational effect with a high degree of accuracy coincides with the initial anomalies. Even with a width of the overhangs up to 3 km the field from the selected model deviates from the initial field by not more than 0.5 mgal, whereas the effect from the overhangs is 2.5 mgal (Fig. 2). It follows from all this that it is virtually impossible to establish the existence of salt overhangs from the gravitational field without using additional data.

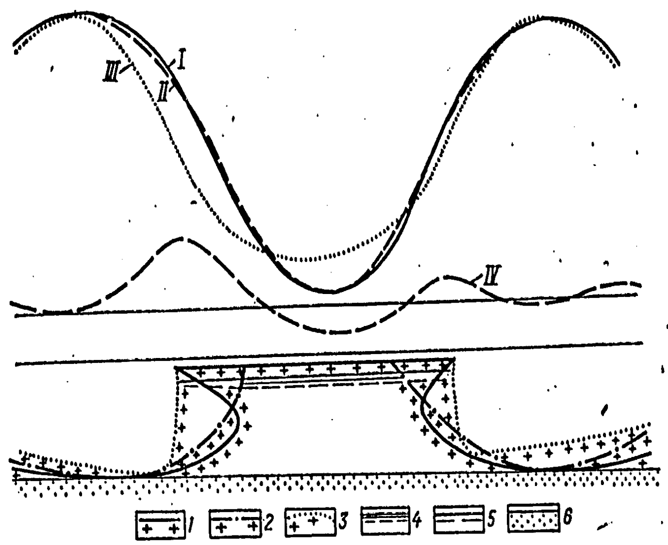

Fig. 2. Results of interpretation of gravity anomaly from model of salt complicated by overhangs. 1) model of top of salt, the anomaly from which was interpreted by the selection method: top of salt obtained as a result of: 2) first variant of interpretation of anomaly; 3) second variant of interpretation of anomaly; 4, 5) "rigidly" determined sectors of top of salt in first and second variants of interpretation respectively; 6) top of subsalt deposits; I-III) anomaly curves Δg corresponding to salt sections 1-3; IV) residual gravity anomaly Δg_{res} (difference in Δg_1 and Δg_2 curves).

Since seismic investigations by the reflected waves method and the common deep point method usually make it possible to map the top of the salt in the arch of the dome, it can be expected that the reflections from it are also traced in the overhang zone. This is confirmed by factual materials in the Begaydar Severnyy area. Here drilling has penetrated a salt overhang in a sector where reflections from the top of the salt have been traced by seismic prospecting by the reflected waves method. It must be emphasized that seismic data for such sectors usually do not give a basis for drawing conclusions concerning the existence of overhangs since the wave field at times corresponding to depths below the top of the salt virtually do not differ from the wave field in the central part of the dome. Cases when it is possible to obtain reflections not only from the upper, but also the lower surface of the overhang (for example, the southern slope of the Kusanbay dome) are rare exceptions.

As a result of this determination of the possibility of tracing the top of the salt in overhang zones by the seismic prospecting method it was possible to solve the inverse problem for anomalies from models of salt domes complicated by overhangs with rigid determination of depths to the top of the salt in the overhang zones. The gravitational field from the selected models essentially does not coincide with the initial curves. The mean square error in selecting the sections for the investigated models was 1.0-2.5 mgal. An increase in the number of approximations does not improve the result.

The curves of the residual anomalies (the differences between the interpreted anomalies and the anomalies from the selected models) are complicated by distinct maxima associated with the marginal parts of the domes, that is, with the overhang zones. The amplitudes of these maxima exceed 1 mgal, but with an overhang width of 3 km attain 5 mgal, which in absolute value considerably exceed the intensity of the anomalies caused by salt overhangs. The nature of the considered maxima of residual anomalies is associated with the gravitational influence of the deposits above the salt, lying under the salt overhangs. The volume of these rocks, under the conditions prevailing in the Caspian depression, can be considerably greater than the volume of the salt overhang lying over them. This is the reason why the amplitudes of the maxima of the residual anomalies observed over the overhangs in absolute value considerably exceed the gravitational effect from the salt overhangs. If, as was demonstrated above, it is virtually impossible to discriminate the anomalies from salt overhangs, the method for detecting gravitational maxima over overhang zones has been worked out quite well and involves the following.

Seismic investigations are made by the common deep-point method. These make it possible to trace the top of the salt in the dome arch up to the steep "bench." The area is covered by a detailed gravimetric survey at a scale of 1:50,000. The gravitational field is interpreted by the selection (trial and error) method with a "Minsk-32" electronic computer using the program described above. In selecting the salt model the depth to the top of the salt, determined by seismic prospecting, is not changed. Curves of the residual field are analyzed; these show the differences between the observed and selected anomalies. The presence of maxima of the residual field over the marginal parts of the domes is an indicator of the existence of a salt overhang. The reliability of this indicator is dependent to a considerable degree on the reliability of seismic data on the structure of the top of the salt in the dome arch.

Work experience shows that there can be errors of two types which can be the reason for both overlooking overhangs and spurious detection of overhangs. For example, in the area of the Zhanatalap Vostochnyy structure the use of seismic prospecting did not make it possible to trace the top of the salt to the edge of the overhang. A salt overhang was penetrated by drilling in a sector where reflections from the top of the salt were not obtained. Under such conditions the additional use of gravimetric data for predicting a salt overhang does not give positive results. In the Kusanbay Zapadnyy sector reflections from the top of the salt were erroneously correlated beyond the limits of the steep salt "bench" in the direction of the zone between the domes. This led to a discrimination of a salt overhang of considerable area in the first stage of interpretation of the gravitational field. Only with a repeated scrutiny of the seismic data was it established that in the correlation of reflections there had been an erroneous switching from the reflecting horizon (the top of the salt) to a horizon which could be identified with the bottom of the Neocomian.

We note in conclusion that neither seismic nor gravimetric data separately make it possible to solve the problem of discriminating salt overhangs. Only the combined use of data from these geophysical methods makes it possible to achieve a definite success. The described method for the interpretation of gravimetric data is coming into practical use on the Gur'yevskaya Geophysical Expedition, which is carrying out a considerable volume of gravimetric prospecting and seismic prospecting work in the territory of the Caspian depression.

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DEPENDENCE OF THE VELOCITY OF AN ELASTIC LONGITUDINAL WAVE ON THE DENSITY OF SEDIMENTARY ROCKS IN FOLDED REGIONS

Moscow RAZVEDOCHNAYA GEOFIZIKA in Russian No 83, 1978 pp 128-133

[Article by G. M. Avchyan and G. O. Aksalyan]

[Text] An investigation of the dependence of the velocity of propagation of a longitudinal wave vp in rocks on their density σ and porosity k_p is necessary when using geophysical methods for studying deep structure of the earth's crust, breakdown of the geological cross section, interpretation of data from acoustic logging, etc.

This dependence has been represented in analytical form by different authors [1-10]. For example, N. N. Puzyrev [6] cites the following relationship between v_p and σ for sandy-clayey and some varieties of calcareous rocks: $v_p = 6\sigma - 11$.

V. M. Berezkin [2], as a result of processing of data on v_p and σ for sandy-clayey rocks from different boreholes on the Russian platform, obtained a quadratic relationship between these parameters

$$\sigma = 1.75 + 0.266v_p - 0.015v_p^2.$$

However, B. P. Belikov [1] notes that there is no general functional relationship between v_p and σ. Due to its stochastic form, I. N. Mikhaylov [4] proposes that use be made of procedures for the statistical processing of data. Thus, available information on the relationship between rocks and their density shows that the investigated dependence is different for different rocks and regions. It should be noted that the mentioned investigations were carried out for rocks of platform regions where the influence of mechanical stresses is caused primarily by geostatic and stratum pressures. In folded regions the influence of tectonic processes causing the diagenesis of rocks and a change in their density leads to a considerable decrease in density and a greater range of change in velocity than in platform regions [3]. Accordingly, it is of great interest to evaluate the possible relationships between vp and σ for sedimentary rocks in folded regions, where there are considerable changes in the stressed state of rocks even at short distances.

The investigated objects were sedimentary rocks from the zone of the Yerevano-Ordubadskiy deep fault in the territory of the Armenian SSR. The fault is well mapped on the basis of the criterion of impairment in the continuity of strata and folds along faults, the presence of mineral springs, travertine shields, some earthquake foci, and most importantly, on the basis of the contrasts of sections on its two sides. The amplitude of displacement of the sides of the fault is about 6 km and thus the permanent nature of its development is emphasized, with a tendency primarily to subsidence of the Yerevano-Ordubadskaya zone.

Rocks, depending on their mineral composition, can be divided into 12 groups and on the basis of structural peculiarities into four groups (see table). The group of aleuropsammitic deposits includes sandstones and tuff sandstones. For sandstones the density values vary from 2.27 to 2.67 g/cm^3, porosity -- from 0.82 to 5.43%, and velocity -- from 3.74 to 5.33 km/sec, whereas for tuff sandstones the corresponding values are from 2.15 to 2.65 g/cm^3, from 1.9 to 17.35%, from 2.89 to 4.53 km/sec (see Table and Fig. 1).

Figure 1,a shows that rocks with a low density have a wide range of velocity change. Whereas in rocks with a density of 2.43 g/cm^3 waves are propagated with a velocity of approximately 2.1 to 4.0 km/sec (that is, vary up to 1.9 kg/sec), with a density of dry rock σ_{dry} = 2.6 g/cm^3 the change in v_p is approximately 0.9 km/sec.

The group of psammoaleurolitic deposits (terrigenous-clastic limestones) included arenaceous, clastic, organogenous-detrital, fine-grained and recrystallized limestones (see table). Arenaceous limestones have densities from 2.46 to 2.69 g/cm^3, porosity -- from 0.27 to 10.2% and velocity from 2.54 to 5.58 km/sec.

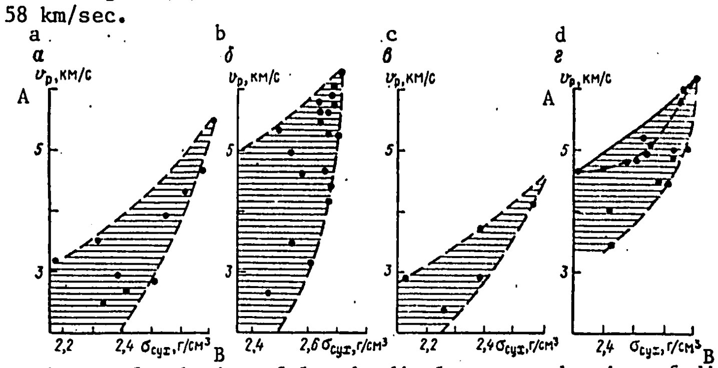

Fig. 1. Dependence of velocity of longitudinal wave on density of different rocks. a) aleuropsammitic (sandstones and tuff sandstones); b) terrigenous-clastic limestones (psammoaleurolitic structure); c) clayey and marly limestones (aleuropelitic structure); d) organogenous-whole shell-detrital limestones.

KEY:

A) v_p, km/sec
B) σ_{dry}, g/cm^3

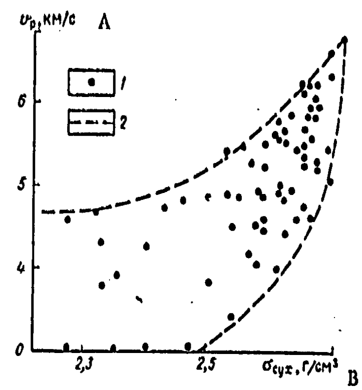

Fig. 2. Dependence of velocity of longitudinal wave on density of different rocks from zone of Yerevano-Ordubadskiy deep fault. 1) experimental data; 2) limits of change in velocity.

KEY:

A) v_p, km/sec
B) σ_{dry}, g/cm^3

Approximately the same σ_{dry}, k_p and vp values are observed for clastic limestones, whereas for organogenous-clastic limestones the density values vary from 2.54 to 2.69 g/cm^3, porosity -- from 0.37 to 6.49%, and velocity -- from 4.5 to 5.45 km/sec. For aleuritic limestone the densities vary from 2.58 to 2.72 g/cm^3, porosity -- from 0.33 to 2.59% and velocity -- from 4.54 to 6.15 km/sec.

Rock Classification	
by structure	by mineral composition
Psammoaleuritic (terrigenous-clastic limestones)	Arenaceous limestones Clastic limestones Organogenous-clastic limestones Aleuritic limestones Recrystallized limestones Fine-grained limestones
Aleuropsammitic (clayey and marly limestones)	Clayey and marly limestones
Organogenous-whole shell-detrital limestones	Organogenous-detrital limestones Organogenous limestones Fine-grained limestones
Aleuropsammitic	Sandstones Tuff sandstones

Fine-grained limestones, in comparison with the remaining rocks in this group, are very dense, fine-pored and have high velocity values (see Fig. 1,b). With a density of 2.4 g/cm^3 the interval of vp change is more than 3 km/sec. This is considerably greater than the interval of change in velocities of aleuropsammitic rocks with an identical density. A similar picture is observed in dependence on the porosity coefficient for the rocks in this group.

Clayey and marly limestones (aleuropsammitic structure) in comparison with terrigenous-clastic limestones have low densities (from 2.11 to 2.59 g/cm^3) and velocities (from 3.03 to 4.63 km/sec) and high porosity coefficients (from 3.67 to 19.2%) [see Fig. 1,c]. With low σ values and high k_p values the limits of velocity change for these rocks are considerably less than for terrigenous-clastic limestones. When σ_{dry} = 2.4 g/cm^3 they constitute approximately 0.8 km/sec.

The group of organogenous-whole shell-detrital rocks includes organogenous-detrital, organogenous and fine-grained limetones. The first have density values from 2.61 to 2.66 g/cm^3, porosity -- from 0.95 to 2.98%, and velocity -- from 4.89 to 5.98 km/sec. Organogenous limestones differ from the rocks considered above in having a relatively broad range of v_p, k_p and σ change. For fine-grained limestones the studied parameters vary accordingly from 2.62 to 2.65 g/cm^3, from 3.46 to 2.97% and from 4.49 to 6.72 km/sec (see Fig. 1,d). For organogenous-whole shell-detrital limestones with a density of 2.4 g/cm^3 the velocity varies in a range up to 1.3 km/sec.

Figure 2 shows curves of the dependence of the velocity of longitudinal waves on density for all the sedimentary rocks which we studied. As for the individual structural groups, with low density and porosity values there is a broad range of velocity change. With σ_{dry} = 2.5 g/cm^3 the limit of change in v_p is 3.1-5.2 km/sec, and with σ_{dry} = 2.7 g/cm^3 the velocity does not exceed 1.0 km/sec.

Thus, analysis of data for the Yerevano-Ordubadskiy deep fault shows that the dependence of v_p on σ and k_p varies. With an identical porosity or density rocks of even the same group have different velocity values.
In order to clarify the reason for the considerable change in v_p for rocks of the same type with an identical density or porosity we studied the influence of pressure p on the velocity of longitudinal waves. Velocity measurements at different pressures were made using a UFS-2 apparatus fabricated at the All-Union Scientific Research Institute of Geophysics. Simultaneously with the registry of v_p we checked the change in rock porosity. It, like for rocks from platform regions, did not exceed 1-2% of the absolute porosity. This made it possible to neglect the change in density from pressure and construct the dependence of v_p on σ_{dry} for different p (Fig. 3). A comparison of the dependence of v_p on σ_{dry} at high pressures with the results presented in Figures 1 and 2 makes it possible to postulate that the considerable interval of change in v_p despite a constant density is a

result of the different stressed state of the rocks. The dependence on k_p can be represented by the equation [9]

$$v_p = \sqrt{\frac{3\,(1-\mu/1+\mu)}{\left[\beta_т + k_п \beta_п \dfrac{\beta_ж - \beta_т}{\beta_п - \beta_ж - \beta_т}\right]\sigma}},$$

[T = sol(id); π = pore; ж = flu(id)] where μ is the Poisson coefficient; β_{sol}, β_{pore}, β_{flu} are the compressibility of the solid phase of the rock, the volume of the pore space and the fluid saturating the rock.

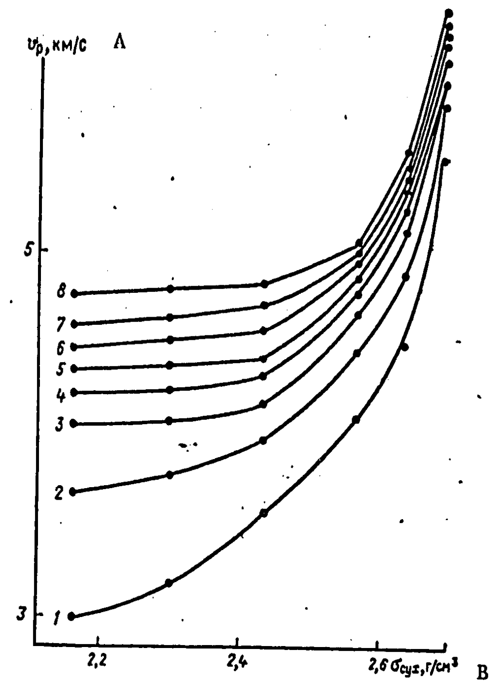

Fig. 3. Dependence of velocity of longitudinal wave on density of limestones for different hydrostatic pressures. p in kg/cm^2: 1) 1; 2) 50; 3) 100; 4) 200; 5) 300; 6) 500; 7) 750; 8) 1000

KEY:

1. vp, km/sec
2. σ_{dry}, g/cm^3

In the case of an identical mineral composition (β_{sol} = const) and density of the rocks the velocity vp is influenced by the compressibility of their pores, that is, rock elasticity, which, as is well known, is dependent on the load on the rock. Accordingly, the dependence of vp on σ for rocks of folded regions will be determined not only by their composition and structure, but also by the pressure at the depth of the rocks. In the future this peculiarity can be used for evaluating, on the basis of joint values v_p and σ, the stressed state of rocks in different sectors of geological structures. As a parameter characterizing the stressed state of rock it is possible to use pore compressibility. For this purpose it is necessary to carry out a broader investigation of the dependence of pore compressibility both on the composition and structure of rocks and on the pressure and temperature acting on the rock in the course of diagenesis.

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IV. UPPER ATMOSPHERE AND SPACE RESEARCH

Translations

MONOGRAPH ON SPACECRAFT CONTROL

Moscow UPRAVLENIYE KOSMICHESKIMI APPARATAMI (Spacecraft Control) in Russian 1978 page numbers not given

[Annotation and table of contents from book by G. D. Smirnov, Izdatel'stvo "Nauka," number of copies not given, 192 pages]

[Text] Annotation. The development of rocket-space technology has dictated the accelerated development of methods, apparatus and systems for the control of space vehicles of different types. Candidate of Technical Sciences G. D. Smirnov tells about this new field of technology in the book. The author describes the spatial-temporal and statistical characteristics of space conditions, the tasks of surface support of space flights are defined, and algorithms for analysis and formulation of solutions relating to the control of space vehicles are described.

Contents

[8144/1495]

MONOGRAPH ON SPACE VEHICLE STABILIZATION

Moscow STABILIZIRUYEMOST' KOSMICHESKIKH LETATEL'NYKH APPARATOV. NOVYYE ZADACHI I METODY (Stabilization of Space Vehicles. New Problems and Methods) in Russian 1978 pp 2, 206-207

[Annotation and table of contents from book by S. V. Cheremnykh, Mashinostroyeniye, 206 pages]

[Text] The book discusses the problems involved in the stabilization of space vehicles in active flight segments from the point of view of some new methods in the theory of control of motion. A new approach is given for investigation of the dynamic properties of space vehicles as a controlled object; this is a development of Kalman controllability and observability theory applicable to this class of objects. Various problems in the analysis of the dynamics of space vehicles encountered in different stages of their planning are considered. The book is intended for engineering and technical workers engaged in the field of rocket and aircraft designing.

Contents

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