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Time Variations in the Geophysical Fields above a Gas Field on Sakhalin Island

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Abstract—Results of repeated geophysical observations above the Yuzhno-Lugovskoye gas field (southern Sakhalin) carried out from 2003 to 2006 are considered. It is shown that the gas field is a natural indicator of geodynamic processes occurring in the gas field and beyond it. A complex of methods and observations is offered to estimate the degree of productivity of the objects involved in prospecting drilling. They provide further development of the short-term forecast of seismic events by geophysical methods, because seismic pulses propagating from an external source cause sharp changes of the geophysical fields above the gas-containing structure.

***Key words*: gravimetry, thermometry, earthquake precursors, geodynamics, gas field, prospecting indicators of oil and gas fields, Sakhalin

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INTRODUCTION

The article describes the results of the first stage of the experiment that was carried out to distinguish the manifestation of the geodynamic processes in geophysical fields; to determine the genesis of these processes; and, finally, to find out the correlation between time variations in the geophysical fields and the seismicity, i.e., revealing the forerunners of seismic events. Within the framework of these problems, it was also planned to obtain reliable forecasting criteria for the presence of oil and gas, which would allow estimating the degree of productivity of prospective objects located in the complex zones of regional disjunctives.

The Yuzhno-Lugovskoye gas field located 4 km west of the settlement of Aniva was selected as the test site for testing new study methods (Fig. 1a).

The Yuzhno-Lugovskoye gas field is confined to the Central Sakhalin regional fault. It is localized among the terrigenous deposits of the Miocene Lower Maruyama subformation (N_{1-2} mr_1) in the eponymous structure (Fig. 1b). The latter is a detachment fold (Fig. 2) formed only in the lower portions of the Lower Maruyama Subformation with an amplitude of a few tens of meters, which decreases upward in the sequence [18].

The gas field is concentrated in 13 horizons of sandstones with satisfactory reservoir properties. The gas (methane) is contained in the horizons from III to XIII inclusively. The horizons from VII to XIII have economic grade gas contents with the main reserves restricted to the lowermost XIII horizon. The thickness of the gas saturated portion of the sequence is no more than 50 m. The structure is approximately 2 km^2 in area. The lower gas–water contact is located at a depth of 1368 m. The total reserves do not exceed 2 billion m^3.

It was initially supposed that the geodynamic characteristics of the deposits (the level of the gas–water contact, the temperature, the pressure in the deposit, and the variation in the density of the gas saturated portion of the sequence) vary in response to a change of the *PT* conditions in the fault zone. The high compressibility coefficient of methane provides a rather high rate of its transport in the porous and massive-fissured media. This in turn should cause rapid changes in the geophysical fields above the gas field, which are available for recording during one season.

During the observations, the gas field was not exploited. Hence, the revealed temporal variations of the geophysical fields were not caused by anthropogenic activity.

High precision gravimetric, thermometric, and magnetometric observations were conducted along three profiles intersecting all the blocks of the Yuzhno-Lugovskoye gas field (Fig. 1b) in order to solve the formulated problems. The profiles of the multidisciplinary geophysical observations were combined with seismic profiles carried out by the Sakhalin geophysical expedition in 1992. The field geophysical observations were conducted from August to November 2003 and from the end of July to October 2004.

Such works in the Russian Far East are being carried out for the first time and are intended for long-term multipurpose use. The interpretation of the obtained materials of the observations represents the results of the first stage of the investigations.

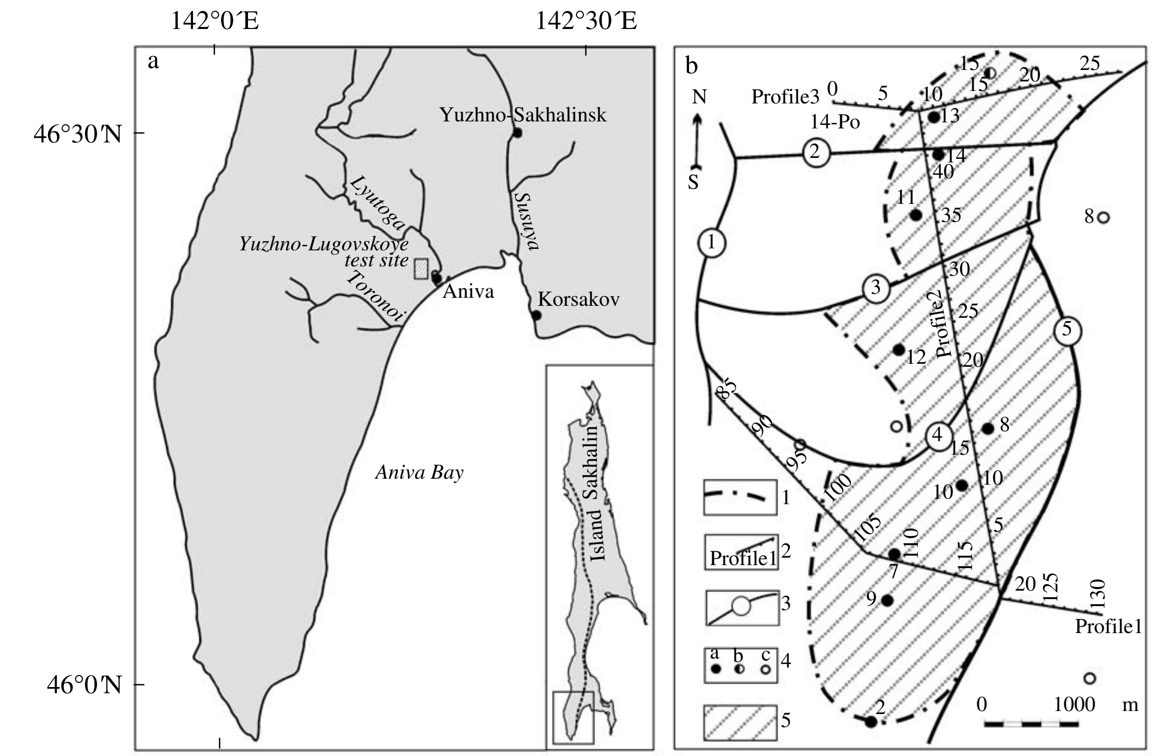

Fig. 1. Geographical location (a) and structural scheme (b) of the Yuzhno-Lugovskoye geodynamic test site in the southern part of Sakhalin (see the inset in Fig. 1a). (*1*) Boundary of the gas fields; (*2*) geophysical profiles; (*3*) main faults based on seismic and drilling data; (*4*) boreholes: (a) with economic influx, (b) with subeconomic influx, and (c) nonproductive; and (5) area of the gas field. The dashed line in the inset in Fig. 1a shows the location of the Central Sakhalin Fault.

BRIEF HISTORY OF THE PREVIOUS INVESTIGATIONS

The performed gravimetric studies are referred to the works aimed at studying nontidal gravity changes that are closely related to the solution of the geodynamic problems. The fundamental studies in this field were carried out by researchers from the Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences and the Institute of Geology and Exploitation of Combustible Fuels of the Ministry of Natural Resources [1, 4–7]. These authors also took the first steps to develop the theoretical basis of nontidal gravity variations and methods of observations and performed large-scale field observations. These studies revealed the gravity instability in the zones of artificial water reservoirs and in the regions where the earth's crust is strained. It was found that the gravity stresses depend on the level of the ground water [4], the height of the tides in the coastal regions, and on other factors, which cause disturbances reaching values from a few to tens of microGals (10^{-8} m/s^2). Stronger temporal variations in the gravity field up to tenths of milliGals (10^{-5} m/s^2) were recorded over large hydrocarbon fields. The highest instabilities were found over gas fields. Thus, it was established that the temporal variations in the gravity field over a deposit depend on the compressibility coefficient of the fluid and its volume [5]. The latter fact served as the basis for the development of methods of prospecting for hydrocarbon deposits based on the effect of the temporal instability of the gravity field [5–7]. These methods and in combination with geochemical methods are successfully applied [1].

Only a few examples of the application of gravimetry for forecasting seismic events are known. For instance, Kh.I. Amirkhanov and S.S. Sardarov (Institute of Geology of Dagestan) [2] carried out an experiment to determine the influence of close earthquakes on the gravity variations at stationary gravimetric stations.

They found from the results of the tidal gravimetric observations that an earthquake followed after three characteristic periods of perturbations of standard tidal waves:

(1) an increase of the gravity field relative to the natural tidal variations depending on the diurnal rotation of the earth;

(2) attainment of the highest gravity acceleration and its subsequent decrease up to stable values;

(3) stable behavior of the gravity field for approximately 20 hours before the seismic event.

Encouraging results were also obtained by researchers from the Institute of Geophysics of Georgia [3], who noted the change in tidal amplitudes during close earthquakes.

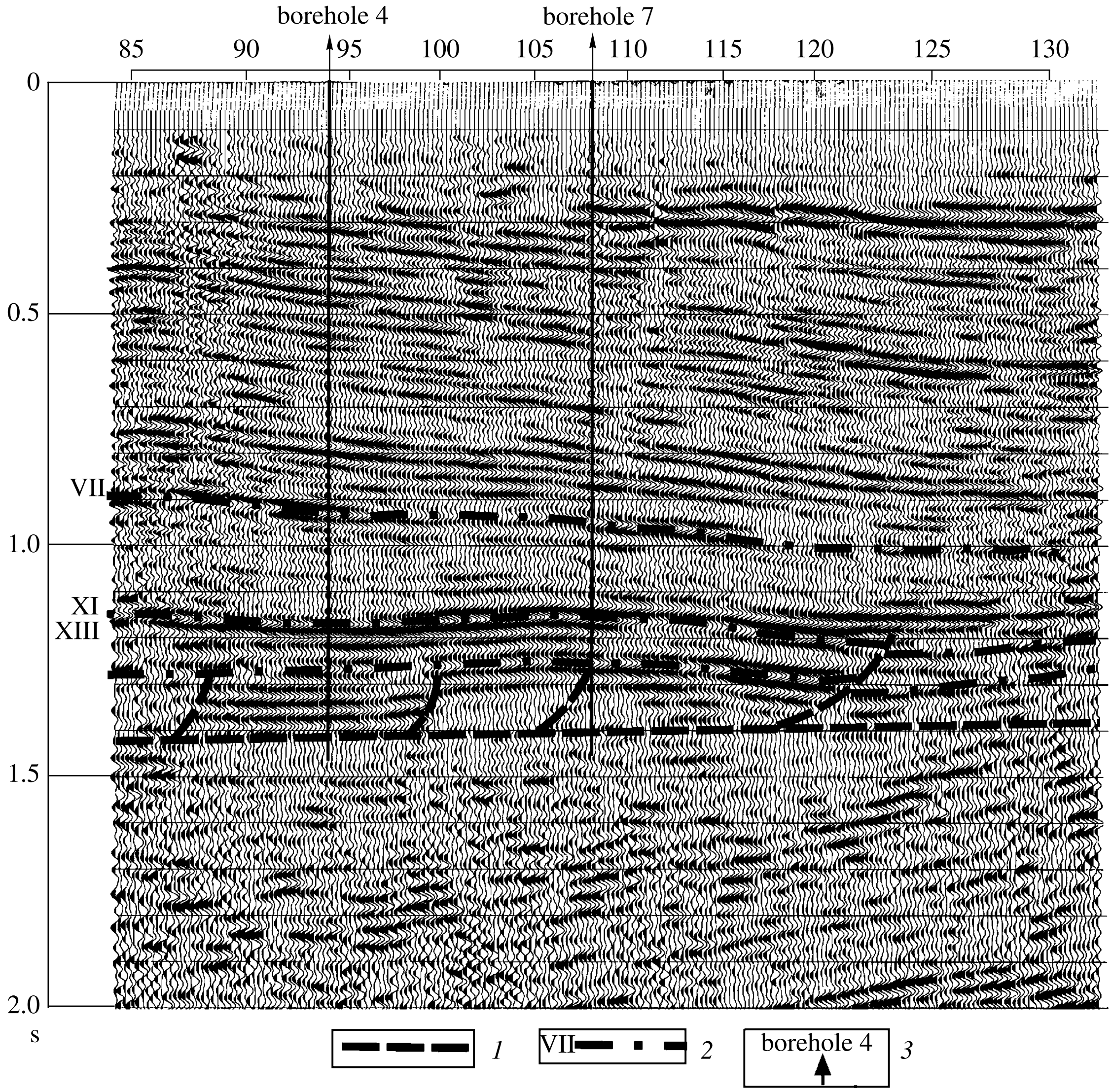

Fig. 2. Seismic time transect along profile 920205b in the interpretation of the authors (combined with profile 1 of the geophysical test site, see Fig. 1b). (*1*) Faults; (*2*) productive layers; (*3*) prospecting boreholes.

Local geothermal anomalies over oil and gas fields were found around the world during numerous investigations [13–16, 22].

The observations demonstrated that local anomalies over hydrocarbon traps are always higher than those above water containing structures.

The geothermal regime of hydrocarbon deposits is strongly influenced by convective processes within the productive bed. According to the calculations of Chekalyuk [23], the temperatures in the domed part of the hydrocarbon reservoir are higher than at the oil- and gas–water contacts, because the ascending flux is typically accumulated in the central part of the gas field and is physically closed at its periphery. This process is most distinctly expressed in the thermal field.

It is assumed that the zones of modern tectonic activity, such as the Central Sakhalin Fault zone, show uninterrupted change of the geotemperature anomaly. The time of the existence of the gas field is of no significance in this case. The intensity of the fluid heat and mass transfer beneath and within the gas field should be greater than the intensity of the dissipation of the energy brought to the surface, which leads to the formation of positive temperature anomalies above the gas field.

The abovementioned factors of the formation of local temperature anomalies over gas fields are the theoretical basis for the discovery of hydrocarbon deposits using temperature fields and the study of the geodynamic state of the Earth's interior in the zones of deep heat and mass transfer.

By the present time, many shallow-depth geothermal methods have been developed for prospecting for hydrocarbon fields. They include studies at the depths of the neutral layer, i.e., the arbitrary depth range of the geological section below which no influence of diurnal and seasonal temperature fluctuations can be recorded [8, 9, 12, 23].

The analysis of the variable temperature field in the near-surface layer of the Earth showed that simultaneous (or within a short time interval) temperature determinations at all the points of the given profile with temperature sensors set at the same depth in ground of similar lithology excluded the influence of solar radiation and all periodic and seasonal fluctuations of the near-surface air. Using this method, the temperature profile reflects the influence of only season-independent deep-seated heat flow.

The analysis of different methods of temperature measurements at different depths showed that the optimal depth of deployment of temperature sensors was 1.5 m, the depth unaffected by the diurnal temperature variations regardless of the ground composition. In addition, it is easy to deploy sensors at the given depth.

The existence of *geomagnetic anomalies* over deposits was known long ago. Usually, these are positive low-intensity perturbations of the geomagnetic field, which can be recorded only by land-based precise observations. They are presently considered as caused by the influence of stratal water of productive layers, which universally has much higher salinity than the water of barren layers. The mobility of peripheral highly mineralized waters and the presence of such chemically active components as CO, CO_2, H_2S, and others in a hydrocarbon reservoir result in the formation of sulfide and iron oxide halos in the country rocks. These halos presumably yield positive geomagnetic anomalies against the lower background values caused by the low magnetic susceptibility of the host sedimentary rocks.

The temporal variations in the geomagnetic and geothermal fields over fluid-bearing geodynamic systems have not been studied yet.

Attempts to trace the variations in the geomagnetic field related to seismic events have been made in many countries, including geodynamic test sites of Middle Asia in the USSR [24]. Magnetometric observations using the methods of repeated routes and repeated regional surveys were carried out at several geodynamic test sites (Tashkent, Fergana, Kyzylkum, and East Fergana). Stationary magnetometric observations were carried out at several points, including the epicenters of strong earthquakes: Gazli (1976), Isfara-Batken (1977), and Tavaksai (1977). Rapid and slow variations were distinguished in the geomagnetic field in response to earthquakes during the period of the observations. It was shown that the variations in the geomagnetic field related to the stages of earthquake preparation have a piezomagnetic, electrokinetic, and electric nature. The prospects of this scientific direction have been reported elsewhere around the world [19].

METHODS OF RESEARCH

Gravimetry. Gravimetric observations were performed with two Russian first-class gravimeters (GNU-KV no. 009 and no. 535). These gravimeters were calibrated prior to the works in July 2003 and July 2004 using the Yuzhno-Sakhalinsk State reference test site over the whole study cycle described in the present-day "Gravimetry Instruction." The main characteristics of the instruments were determined from the calibration data: the scale division, its temperature dependence, the root-mean-square error of single observations (±0.02 mGal for each of the tested gravimeters), and the time period of the linear drift of the zero-point (no less than three hours for each of the instruments at a controlled temperature).

The gravimetric measurements included five cycles along three preliminarily prepared profiles with observation steps of 50 and 100 m and a one-month gap for each season between the cycles. The fourth and fifth cycles of the observations (August and September 2004) were carried out only along profile 1, which was extended 700 m to the northwest and 600 m to the east relative to the position of the profile in 2003.

Two gravimeters were used simultaneously in each cycle. Thus, the total root-mean-square measurement error of the observed values at the points of the test site in each cycle practically did not exceed the instrumental error (±0.018 mGal in cycle 1, ±0.016 mGal in cycle 2, ±0.022 mGal in cycle 3, ±0.017 mGal in cycle 4, and ±0.019 mGal in cycle 5). In 2003, time series of 420 observations were performed at 69 points. In 2004, two cycles of observations were performed at 46 points of profile 1 and involved 278 measurements.

The single step reference gravimetric network was developed before each cycle of observations with three–four independent routes using two instruments simultaneously from one initial reference point located in the northwestern extremity of profile 1, far away from the western boundary of the gas field.

The points of the reference network were located in such a manner that the observation time in an ordinary unit of the gravimetric cruise was no more than 30 minutes. The root-mean-square determination error of the observed values of the gravimetric field (Δg_{obs}) over the reference network in each cycle of observations was no more than ±9 μGal.

The presented data indicate that anomalies of the differences of the observed field with intensity greater than 0.02 mGal are reliable.

The characteristics of the measurement accuracy of the observed gravity values should be supplemented with the fact that, in the beginning of October 2004, the observations were simultaneously carried out at five reference points of profile 1 using LaCoste-Romberg and previously applied gravimeters. The maximal deviation of the mean values based on the measurements with GNU-KV gravimeters from the values obtained by the LaCoste-Romberg gravimeter were taken as reference ones and accounted for 4 μGal.

All the gravimetric observations were performed at an arbitrary level without assignment to the state reference network.

Thermometry. Thermometric observations were conducted using Russian electric thermometers (TET-2) pressed in aluminum pipes. Before the field works, the temperature sensors were testified under laboratory conditions using reference mercury thermometers (TR-1). The measurements were carried out in boreholes 1.5 m deep integrated with the points of gravimetric observations. The measurement accuracy was ±0.05°C. In 2003, three full cycles of measurements were made at the Yuzhno-Lugovskoye test site; in 2004, four full cycles were made along profile 1. The temperatures were measured no less than 30 minutes after deploying the sensors into the boreholes. The measurements of each profile in the current cycle were made at all the points during one day.

Magnetometry. Magnetometric observations were carried out using magnetometers (MMP-203) applying the single measurement method over the intervals of the profile of the Yuzhno-Lugovskoye test site, which are devoid of technogenic pollution (profiles 1 and 2), with simultaneous recording of the magnetic field variations. The accuracy of the anomaly determinations was ΔTa equals ±2 nT.

RESULTS

Similar variations of the gravity and thermal fields were recorded along all three profiles of the test site, which indicates that the target location of the deposit is reliably detected from the characteristic set of indicators. Since the largest body of data was accumulated along profile 1, which most representatively characterizes the field variations above the deposit, including those caused by the seismic event on September 13, 2004, below, we consider exactly these materials.

Time variations in the gravity field. The gravity differences between cycles of observations at the Yuzhno-Lugovskoye gas field were calculated from obtained gravimetric data. In order to trace the temporal gravity field variations, the values of the previous cycles were subtracted from the values of each new cycle of measurements.

The results obtained indicate that the gravity field within the deposit varied with time. The differences between the observed values in the different cycles reached 0.12–0.15 mGal along all three profiles of the test site. It was noted that the distribution of extremely high values of the differences within the field was different. The field blocks bounded by faults along the productive bed XIII (Fig. 2) are manifested by the maximal differences Δg_{obs}. The boundaries of the blocks correspond to either zero difference, narrow extrema, or changes in the sign of the differences Δg_{obs} (Fig. 3). In particular, the plots of the distribution of the differences Δg_{obs} along profile 1 distinctly demonstrate the boundaries of the field blocks at points 98–100, 108, and 120. These points show a change in the difference distribution. Additionally, they correspond to the projection of the intersection between faults and layer XIII, whose roof is shown in time seismic transect 920205b (Fig. 2) combined with profile 1. This regularity is also observed for other profiles of the test site.

Another anomaly of differences, which probably corresponds to the local field revealed in 1971 (borehole no. 1) (Fig. 3d) was distinguished at the eastern flank of profile 1 (points 127–130). The borehole is located 300 m south of this part of the profile. The eastern extremity of the anomaly has not been revealed so far.

The Δg_{obs} differences of the profile segments located over nonproductive blocks of the transect are within the measurement accuracy and could not be regarded as anomalies.

In order to estimate the reliability of the distinguished gravity effects, we solved the direct gravimetric problem [18] in the two-dimensional version of an idealized model in which a deposit 50 m thick was approximated by a rectangle with its lower side subsided to a depth of 1370 m with its length corresponding to the intersection segment of the field by profile 1.

The calculations showed that a ±0.05 g/cm^3 change of density in the field block resulted in a ±0.10–0.11 mGal change in the gravity field. The same values were obtained by calculations using the method of A.I. Volgina [5].

The following conclusions can be drawn from the obtained results of the gravimetric observations:

(1) It was found that the gravity field over the gas reservoir varied with time.

(2) The time variations of the gravity field over the gas field reach 0.12–0.15 mGal.

(3) The character of the time variations in the gravity field emphasizes the inhomogeneity of the gas field and can be used for outlining the blocks of the gas-saturated structure with individual geodynamic parameters.

Temperature variations. The results of multiyear thermometric observations at the Yuzhno-Lugovskoye test site showed a gradual seasonal decrease in the daily mean temperatures from the end of August to April in the near-surface layer of 1.5 m, the depth of our measurements [20]. This period of seasonal temperature variations involves temperature observations carried out at the test site in 2003 and 2004. The temperature curves obtained in different cycles at the same observation points are sequentially lower by the absolute values but, in general, preserve the configuration (Fig. 4).

A clear correlation of the relative temperature maxima with the areas of anomalous gravity differences was found from the results of the temperature observations in 2003. In addition, it was established that the

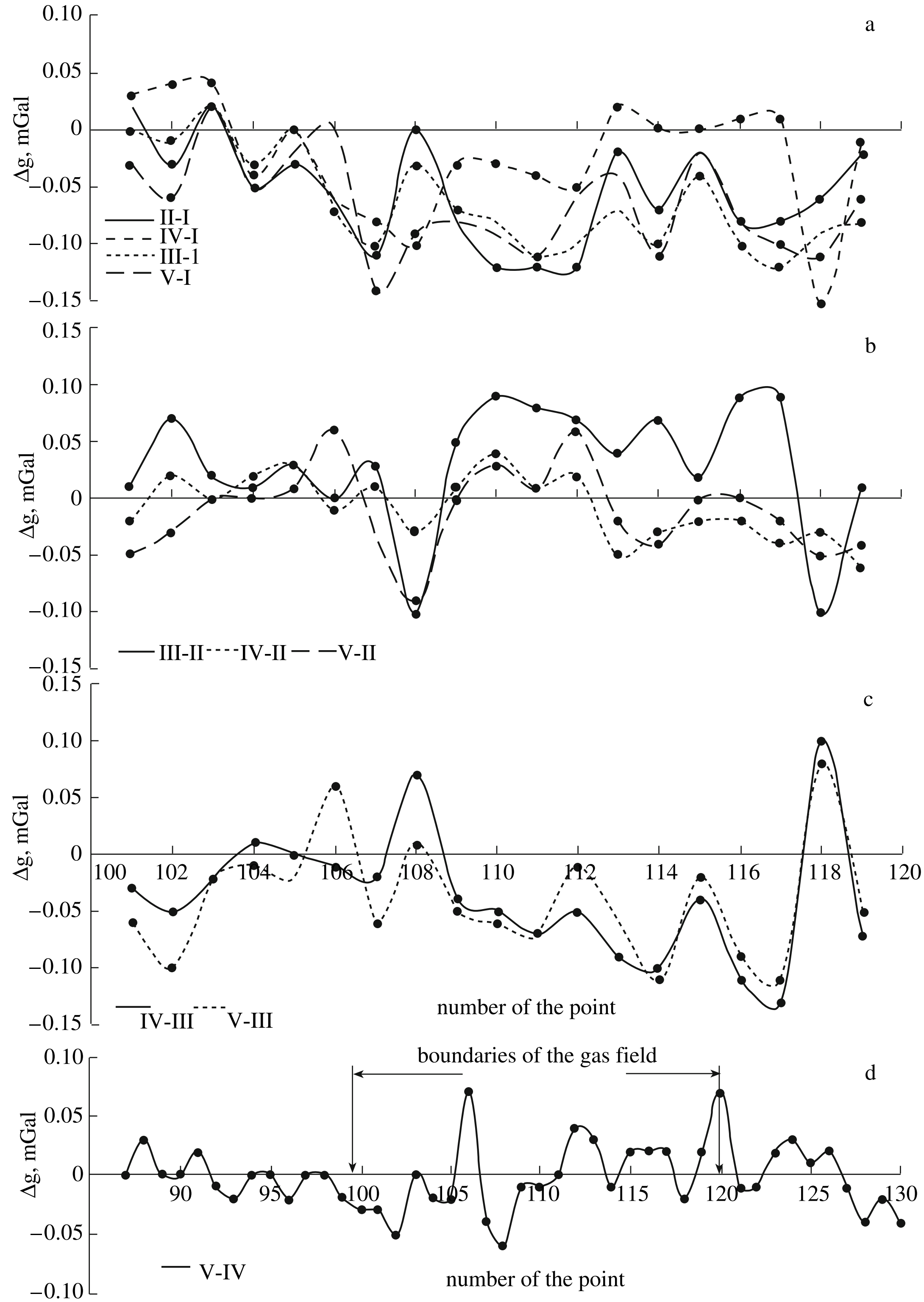

Fig. 3. Gravity differences between cycles of observations along profile 1:
(a) with respect to cycle I: (b) with respect to cycle II; (c) with respect to cycle III; (d) with respect to cycle IV

points of the gravity changes practically always correspond to the intervals of narrow local minima of the thermal field. In this case, the extreme points of the temperature minima are only insignificantly displaced (by 1–2 steps of observations) relative to the points with near-zero differences.

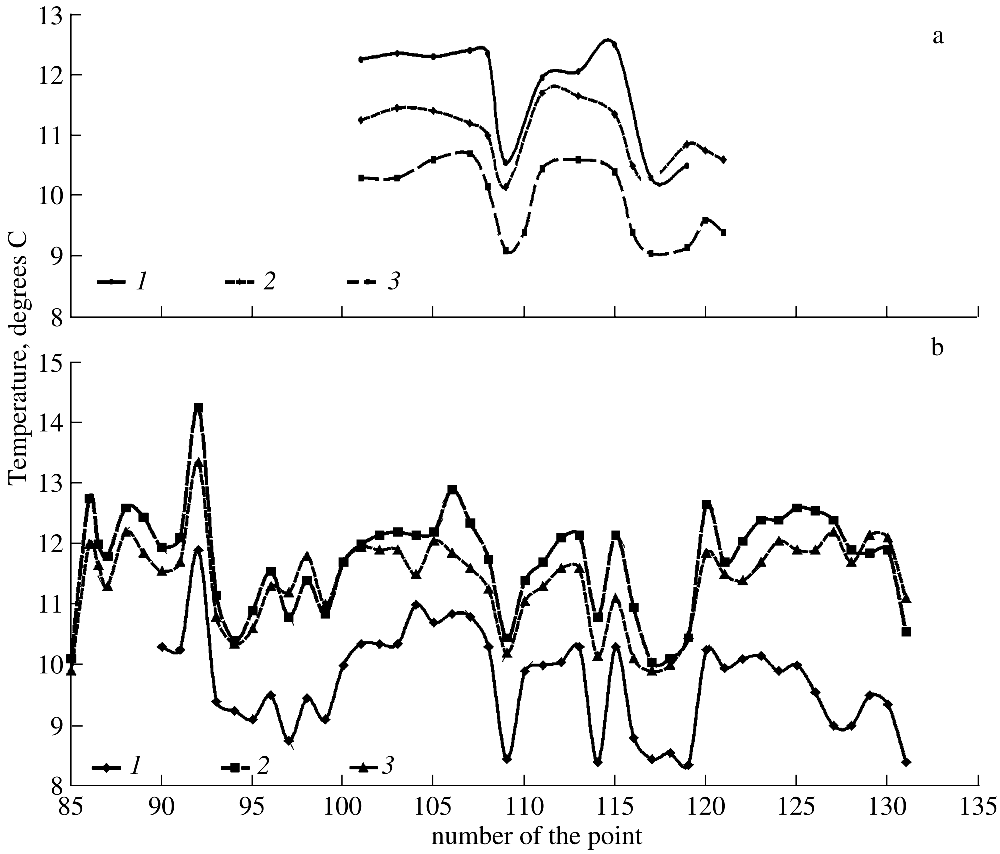

Fig. 4. Temperature graphs along profile 1. (a) Measurements in 2003: line 1 (measurements on September 1–8), line 2 (measurements on October 11), and line 3 (measurements on October 27); (b) measurements in 2004: line 1 (measurements on July 1–25), line 2 (measurements on September 2–12), and line 3 (measurements on October 8).

The found regularity, however, is true only within the gas field. The results of the observations carried out in 2004 beyond the gas field revealed one more relative temperature maximum (points 85–93) whose intensity is comparable with that of the maxima confined to the western and eastern blocks of the gas field. Thus, the found tendency of the general (background) increase in the thermal field toward the Central Sakhalin Fault, which is located approximately 1–1.5 km west of the test site, requires the following specifications to be made. The relative temperature maxima that are correlated with the gravity difference maxima can be considered as reliable prospecting criterion. The profiles located in distinctly nonproductive blocks don't show any gravity perturbations and correlation of the latter with the temperature data.

The most striking manifestation of the gas field in the thermal field was recorded during the earthquake on September 13, 2004. We recorded this event during gravimetric observations at 14:02 local time (03:02 GMT). The epicenter of the earthquake was located 600 km southeast of the Yuzhno-Lugovskoye test site. The event was expressed in sharp aperiodic fluctuations of the measuring systems of gravimeters, which lasted more than four hours and then became indistinguishable from the oscillations caused by the incipient storm. At the time mentioned above, this event was recorded by autonomous seismic stations at two points located in the small town of Ozhidaevo and in Yuzhno-Sakhalinsk (40 km north-northwest and 40 km northeast of the test site, respectively). The parameters of the event were written about in seismological bulletin no. 26 (from September 11 to 20, 2004). The thermometric observations carried out along profile 1 on September 12, 2004, from 14:31 to 18:27 local time (less than one day before the event mentioned here) were repeated on September 15, 2004, from 09:37 to 12:40. The comparison of the results of these two series of observations (Fig. 5) showed a 0.5–0.8°C temperature increase within the gas field (points 100–119), which contradicts the established regularity of their seasonal decrease. At the same time, the profile intervals over certainly nonproductive blocks of the section demonstrate a systematic temperature decrease by 0.1–0.15°C. In the eastern flank of profile 1 (points 128–131), the same series of observations revealed one more positive temperature anomaly, which most likely corresponds to the western part of the local gas field found during drilling of prospecting borehole no. 1 in the Zolotorybnaya area in 1971. The borehole is located 300 meters south of the anomalous

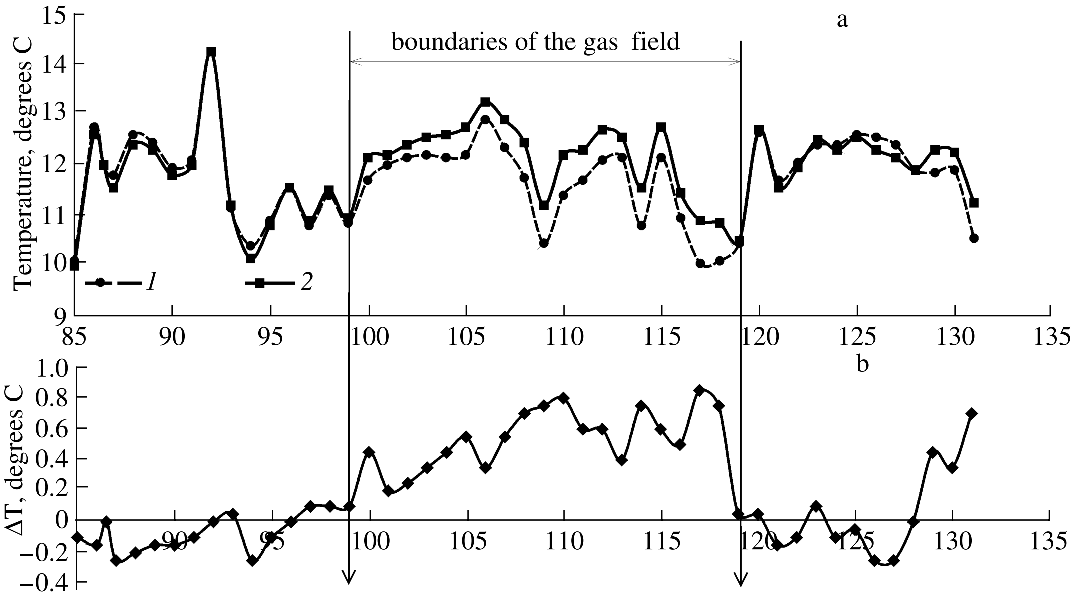

Fig. 5. Temperature variations along profile 1 before and after the earthquake on September 13, 2004. (a) Temperatures before the earthquake (1) and after the earthquake (2); (b) temperature differences (2–1).

interval of the profile (Fig. 1b). In this area, the temperature anomaly is also accompanied by elevated gravity differences between the fifth and fourth cycles of observations. The eastern closure of the anomaly is planned to be traced during the further works.

Noting the sharp temperature inversion over the gas field, it's not a necessity that its onset coincides with the time of the seismic pulse propagation. Using numerous examples, D.G. Osika [17] demonstrated that an increase in the debits of different fluids in the boreholes and a temperature increase at the sources located in seismically active zones occured a few days before an earthquake. It is not excluded in this case that a 0.7–0.8°C increase in the thermal field over a gas field less than two days before an event is only an interval against the general background increase of temperatures in response to the active phase of the seismic event preparation.

Continuing the consideration of the thermometric observation results, let us examine in detail the following.

Simultaneous thermometric and gravimetric observations were performed only during the second and third cycles. In this case, the synchronism in these observations allows their comparison.

Some differences in the form of the temperature curves (Fig. 4a; curves 2, 3) can be caused by several reasons:

(1) Several incessant rains occurred between the cycles of observations in 2003. Under conditions of a hard sink of the upper layer of the ground water caused by the smoothed topography and lithology of the quarter sediments within the test site, they could lead to a different degree of flooding of the same blast holes and, correspondingly, to different thermal conductivity of the recovered rocks.

(2) The differences in the curve shapes are caused by temporal variations in the thermal field induced by the dynamics of heat and mass transfer within the object studied.

The comparison of the temperature differences between the third and second cycles of observations with the Δg_{obs} differences in the same succession (Fig. 6) indicates practically similar changes of the gravity and thermal fields over the studied object. In addition, the differences between the thermometric observations in the named cycles in terms of their distribution correspond to definite blocks of the structure whose boundaries were determined earlier.

According to our data, experimental studies in this field have not been carried out yet and the described effect was found for the first time. However, some researchers [11, 21, 25] showed that the anomalies of the heat flow and gravity force were related via the dynamics of the thermal regime and density changes caused by heat and mass transfer. Transforming these relations for a plane-parallel layer yields [18]

$$\Delta g_{\mathrm{B}} = 2\pi f \Delta\rho \frac{\lambda \Delta T}{q \Delta z} = 2\pi f \Delta\rho H,$$

where Δg_{B} is the gravity anomaly in the Bouguer reduction, f is the gravity constant, q is the thermal generation of a unit volume of the source, λ is the coefficient of the effective thermal conductivity of the medium, H is the thickness of the fluid-bearing layer, $\Delta\rho$ is the change in

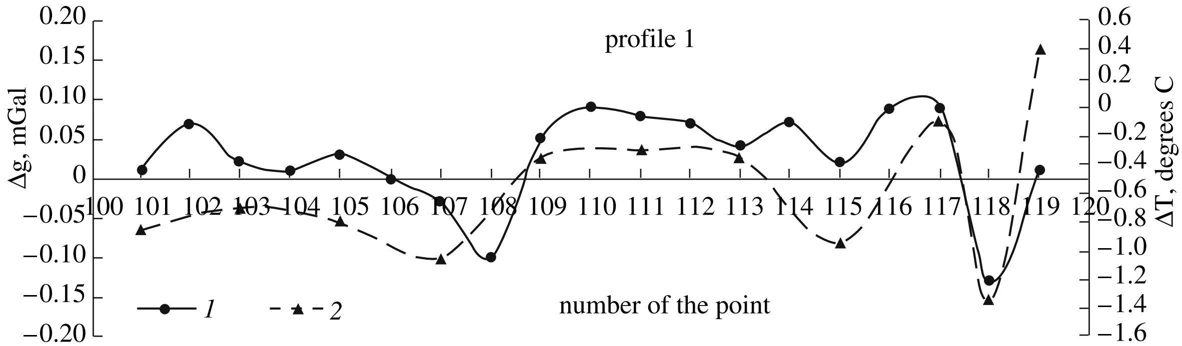

Fig. 6. Graphs of synchronous variation in the observed gravities and temperatures along profile 1 between cycles of observations III and II. (*1*) gravity differences; (*2*) temperature differences.

the medium density, and $\frac{\Delta T}{\Delta z}$ is the geothermal gradient.

It was shown by the example of the earthquake on September 13, 2004, that, at $\lambda_{mean} = 1.32$ W/(m · K) (for a predominantly mudstone composition), $H = 40$ m, and $\Delta g_B = 0.1$ mGal, the density variation in the fluid-containing layer reached 0.06 g/cm^3 [18].

When the temperature increment in the layer is 0.8 K (a 20 mK/m increase in the thermal gradient), the specific heat generation in the layer volume determined from the relation $q = \frac{\lambda \Delta T}{H \Delta z}$ is 0.66 mW/m^3.

This value is more than 500 times higher than the background specific heat generation caused by radioactive decay in the mudstone-bearing sequence, which indicates a powerful thermal hydrodynamic influence on the fluid-bearing sequence within the gas-bearing region during the propagation of the elastic oscillations from the earthquake source.

According to the above estimates, the influx of aqueous solution caused by the seismic event on September 13, 2004, in the southern part of the Yuzhno-Lugovskoye gas-bearing field was approximately 280 th. m^3 and led to the water level rising by 240 cm.

The main results of the thermometric observations at the Yuzhno-Lugovskoye test site are as follows:

(1) The blocks of the gas-saturated structure are manifested in the thermal field as relative temperature maxima, which correspond to the areas with an extremely high gravity difference.

(2) The boundaries of the gas-saturated blocks with individual geodynamic parameters are expressed as narrow relative temperature minima. They are located in the regions of the temporal gravity change.

(3) The temperature distribution over the gas-saturated structure depends on its geodynamic state, while the temperatures proper increase during the propagation of a seismic pulse.

(4) The temperature field changes its configuration over the gas-saturated structure synchronously with the change in the configuration of the gravity field.

Geomagnetic observations. Owing to the excessive technogenic pollution at the Yuzhno-Lugovskoye test site, informative geomagnetic observations can be obtained only along profile no. 1. In this area, the relative maxima of the geomagnetic field are visually correlated both with the relative temperature maxima and the gravity difference maxima, while the local minima ΔT_a correspond to the inflection points of other geophysical fields. Thus, the distribution of anomalies ΔT_a emphasizes the peculiarities of the gravity and thermal fields and generally confirms the heterogeneity of the studied object.

No evident time variations in the geomagnetic field were found over the gas field at this stage of the work, indicating the subsidiary role of magnetometry in developing prospecting criteria.

More important results were obtained using magnetometric methods in distinguishing the forerunners of seismic events. For example, the usual magnetometric observations along profile 1 and simultaneous recording of geomagnetic variations during the seismic activity on September 13, 2004, demonstrated that variations in the strength of the geomagnetic field strongly depended on the stress level in the earth's crust. It is clearly seen (Fig. 7) that a sharp increase in the strength of the field ΔT_a began at 13:25, i.e., 37 minutes before the seismic event. The event (the time 14:02 is indicated with an arrow on the graph) is not manifested against the background of the linearly increasing values of the geomagnetic field recorded at the reference point with a 5-min interval. However, during the ordinary observations along the profile, a series of measurements were recorded by the second magnetometer in the same time interval at points 90–96 (Fig. 7a, 7b). The time intervals between the records in each series equal the standard time of the measurement stabilization, i.e., 10–15 s. The graphs of ΔT_a based on the series of observations revealed the sharply heterogeneous character of the short-term variations in the geomagnetic field. They

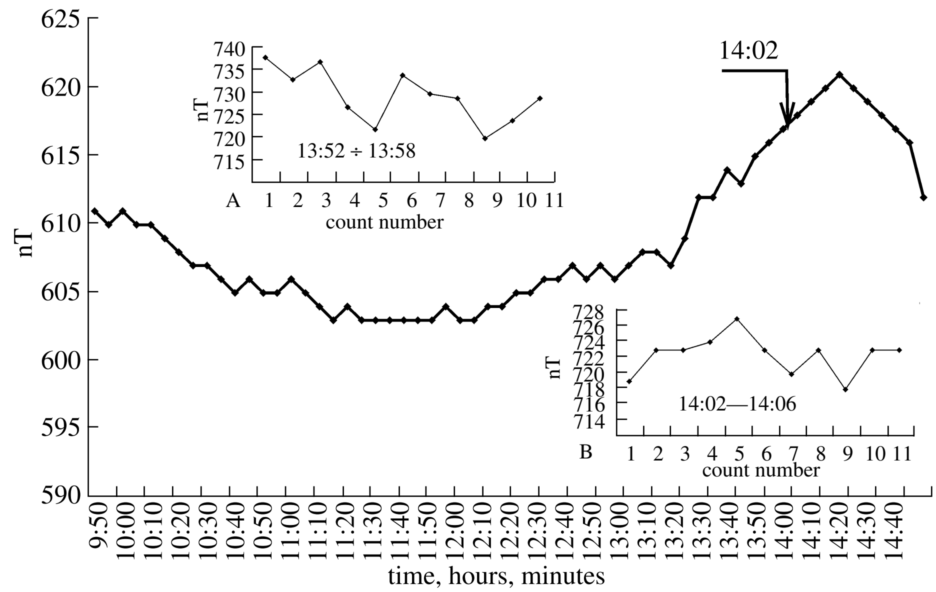

Fig. 7. Graphs of the geomagnetic variations on September 13, 2004.

presumably represent uneven pulses in which the periods of the short-term (~20–25 s) stabilization of the field alternate with the periods of a sharp increase and a sharp decrease of the field strength. The oscillations of the field with the greatest amplitude (up to 20 nT) were recorded in the time interval of 13:52–13:58 (Fig. 7a).

No regularities were found in the recorded episodes of the variations in the geomagnetic field during the seismic event. Nevertheless, the obtained data allow us to suppose the following:

(1) The shape of the recorded variation anomaly does not correspond to that caused by the short-term increase in the solar activity. It is possible that the anomaly was formed by induction that appears during the propagation of a strong electric pulse. The latter in turn could arise from the piezoelectric effect (or seismoelectric effect of the second type), which is related to the fast deformations in the earth's crust.

(2) The interval episodes of magnetic variations (Fig. 7a, 7b) suggest that a continuous record with accuracy not worse than ±0.1 nT could identify geomagnetic variations that mark the preparation of a seismic event from the initial to the final stages.

(3) While record of the geomagnetic variations, the fluctuations of the total vector T could usefully be supplemented with recording the oscillations of its Z and H components and fluctuations of the natural electric field.

CONCLUSIONS

(1) It was found during the work that the target location of even an insignificant hydrocarbon reservoir was reliably identified by the complex of repeated high-precision gravimetric and temperature observations regardless of the type of trap and the hydrocarbon composition. The oils of the Far East are usually characterized by a gas factor (gas content) up to 200 m^3/m^3 and more, which corresponds to sufficiently high compressibility coefficients (not less than 5 GPa^{-1}) and elastic capacity.

(2) The reliable criteria for the presence of hydrocarbons in the studied object are the following: (a) the spatially constrained instability of the gravity field up to ±0.05mGal and more, (b) the coincidence of the relative temperature maxima with the regions of anomalous gravity instability, and (c) the presence of regions with synchronous time variations in the gravity and thermal fields.

(3) The highest amplitude variations of the geophysical fields over a gas field are recorded during the propagation of a seismic pulse. This period is marked by changes in the gas–water contact level and the temperature and pressure within the gas field. This leads to a change in the density of the gas-saturated beds, i.e., changes in the geodynamic state of the gas field.

(4) Forecasts of the oil and gas potential and seismic events in this case are interrelated problems. On the one hand, the gas field is clearly manifested during the propagation of a seismic pulse and, on the other hand, variations in the geophysical fields over the gas field can provide an opportunity to trace the seismic event preparation.

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