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Experience in Registration of Variations Caused by Strong Earthquakes in the Level and Physicochemical Parameters of Ground Waters in the Piezometric Wells: the Case of Kamchatka

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Abstract—The hardware complex that was produced by OOO Polynom, Khabarovsk, for registration of the level, temperature, and electrical conductivity of ground water in wells and meteorological parameters (atmospheric pressure, air temperature) at a measurement frequency from 5 min to 1 h is described. The equipment is installed in the wells of Kamchatka and has been used for several years to register variations caused by earthquakes in the parameters of ground waters. Different variations in measured parameters of ground waters due to strong earthquakes of February 28, 2013, $M_W = 6.8$ and May 24, 2013, $M_W = 8.3$ are registered with this equipment in wells YuZ-5 and E-1. The registered variations and their systematization are described taking into account the mechanisms of a seismic impact on the state of the well—water-saturated rock system.

Keywords: well, water level, electrical conductivity, hardware complex, earthquake, Kamchatka

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INTRODUCTION

Strong earthquakes can be accompanied by different variations in the levels, temperature, and chemical composition of ground water in wells. In Kolylova (2006, 2010), we termed them *hydrogeoseismic variations* and showed that the features of their manifestation are determined by different seismic impacts on the state of the "well—water-saturated rock" system.

The changes in the static stress field during the formation of ruptures in the earthquake foci and corresponding variations in the stress-strain state of the water-saturated rocks manifest themselves in coseismic jumps of the increase or decrease in the water level during the first few minutes after the arrival of seismic waves. Dynamic strain of water-saturated rocks and shaking of a well bore can also be accompanied by various co- and postseismic effects in the changes of levels and chemical composition of ground waters under the passage of seismic waves from strong earthquakes. Such effects are described in numerous works, e.g., Kopylova, 2001, 2006; Kopylova et al., 1994; Wang and Manga, 2010. When studying them, the researchers focus their attention primarily on the explanation of hydrogeodynamic and hydrogeochemical processes of their formation and general estimation of an impact of strong earthquakes on the state of the fluid-saturated geological medium.

During performance of observations in the wells of Kamchatka and other seismoactive regions, the changes in the state of ground waters that manifest themselves before strong earthquakes (or hydrogeological precursors) are of especial scientific and practical interest, since they can be used to predict strong earthquakes and to specify the time of such events (Kopylova, 2001, 2006a, 2006b, 2010; Kopylova and Boldina, 2012; Kopylova et al., 1994; Wang and Manga, 2010).

The Kamchatka Branch, Geophysical Survey, Russian Academy of Sciences (KB GS RAS) performs observations of changes in the physicochemical parameters of ground water in the wells in order to find earthquake precursors and other seismic effects. When using the well observation data to make seismic predictions and to reliably register effects from seismic waves, we should use precision measuring instruments for monitoring under field conditions in the near real time mode. At the Kamchatka Branch, Geophysical Survey, Russian Academy of Sciences, observations are made in piezometric wells by the hardware systems developed at OOO Polynom, Khabarovsk. They provide synchronous measurements of water level, temperature, and electrical conductivity as well as meteorological parameters, such as atmospheric pressure

Table 1. Parameters of strong earthquakes in Kamchatka in 2013 (*Sil'nye*..., 2014)

Hypocenter					Energy class/magnitude						R, km	Points on MSK-64
Date Month/date/yr	Time h:min:s	N	E	H, km	KB GS RAS			Global CMT	NEIC (USGS)			
					K_S	ML	M_C	M_W	mb	M_W		
Feb. 28, 2013	14:05:48	50.67	157.77	61	15.2	6.9	6.6	6.8	6.4	6.9	265	4–5
May 24, 2013	05:44:47	54.76	153.79	630	17.0	7.8	8.3	8.3	7.5	8.3	370	4–5

and air temperature, at a rate of inquiry interval from 5 min to 1 h (Kalinov et al., 2012).

Using the published materials (Kalinov et al., 2000, 2012; Rimlyand et al., 2000) in our work, we present technical characteristics of the major elements in the measuring system as well as the examples of hydrogeoseismic variations in the water level, temperature, and electrical conductivity that were recorded in wells YuZ-5 (depth of 800 m, level at a depth of 1 m below the head) and E-1 (depth of 665 m, level at a depth 27 m) in connection with the strong earthquakes that occurred on March 28, 2013, $M_W = 6.8$ and May 24, 2013, $M_W = 8.3$ (Fig. 1, table 1). The data on the well structures and local hydrogeological conditions are presented in Kopylova (2001, 2006a) and on the website of Kamchatka Branch, Geophysical Survey, Russian Academy of Sciences, at http://emsd.ru/lgi/places/e1 and http://emsd.ru/lgi/places/uz5.

The hydrogeological and meteorological parameters were measured at an interval of 5 min. The data are transferred to Kamchatka Branch, Geophysical Survey, Russian Academy of Sciences, every hour and are processed at the branch's laboratory of geophysical research on a daily basis. The results of processing (initial and purified from the influence of distortion factors), which are represented as plots of time series of water level variations, are uploaded daily to the branch's website http://emsd.ru/lgi/observations.

EQUIPMENT

In 2013, monitoring of wells YuZ-5 and E-1 was performed using Kedr-DM-U hardware system (OOO Polynom, the city of Khabarovsk) with the subsequent telemetry transmission of data to the Kamchatka Branch, Geophysical Survey, Russian Academy of Sciences, via the public mobile communication channels (*Kedr-DM*..., 2007; Kalinov et al., 2012).

Kedr-DM-U consists of a highly sensitive ultrasonic water level sensor (a level indicator) for registration of variations in water level accurate to ±0.1 mm and a downhole probe for measuring electrical conductivity and temperature of ground water. The sensors of atmospheric pressure and air temperature are included into a BSI 300 registration unit that is mounted above the well head. Figure 2 presents the scheme of mounting the measurement system on the wells.

The main unit of the measurement system is a system of registration of a water level in the wellbore. Kedr-A2-U and Kedr-DM-U variants were used for level-measuring observations at Kamchatka Branch, Geophysical Survey, Russian Academy of Sciences. They measure water level by an ultrasonic level indicator (Figs. 2b, 2c). Letters A and DM denote the ways of information storing and transmission from observation wells. Kedr-A2 stores results of measurements in a portable module of energy-dependent memory; information is transmitted by replacing the data accumulator. Kedr-DM has a telemetry channel based on mobile or satellite communication.

Ultrasonic well level indicator (Kalinov et al., 2000, 2012; Rimlyand et al., 2000). The method for determining water level is based on measuring the time of ultrasonic pulse propagation (USP) in a vertical sound duct. The sound duct is a thin metal rod. In this case, a USP is formed immediately at the liquid-air interface (Kalinov et al., 2000).

The well level indicator (Figs. 2b, 2c) consists of a housing represented by a protective pipe with a diameter of 51 mm and a length of up to 3 m; a vertical sound duct-rod pulled at the center of the protective pipe; a float emitting ultrasonic pulses that coaxially covers the rod and freely moves along it; a power unit, a synchronizer, and a receiving block of ultrasonic pulses fastened to the upper end of the rod; and a reference USP emitter fixed to the bottom end of the rod. The level indicator descends into the well with a special cable. On the ground surface above the well head, there is a BSI data collection unit (logger) (Figs. 2a, 2c) that maintains a contact through the cable.

A USP is excited by ring-shaped piezoceramics that coaxially covers the sound duct. An electric pulse generated by the special electric scheme located in the float is sent to piezoceramics synchronously with starting a time counter. A special system was developed based on the induction method to supply power and synchronize a process of acoustic pulse emission (Kalinov et al., 2000, 2012). A metal rod, a sound duct, and a protective pipe were used as the primary coil of the transformer. The secondary coil of the transformer is located inside the body of the float.

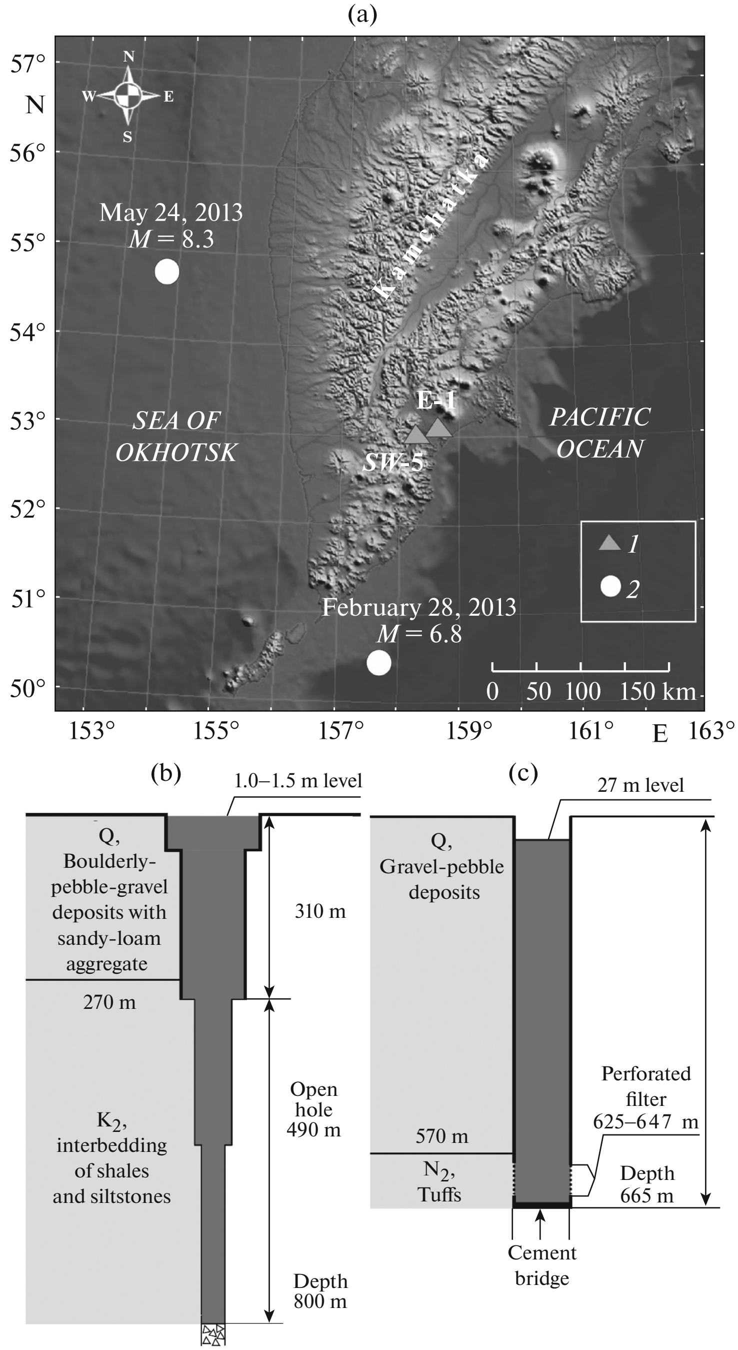

Fig. 1. Location of observation wells and epicenters of the strong earthquakes in 2013 (Table 1) (a); structure of well YuZ-5 (b) and well E-1 (c) with the description of water-saturated rocks. (*1*) Well and (*2*) earthquake epicenter.

The induced signal is split in time into a power signal that charges the storage capacitor and a synchronization pulse. The emitter is turned on with a time delay with respect to a signal of a charge and continues for 100 μs.

Figure 3a presents a functional scheme of power supply and synchronization of the ultrasonic emitter (Kalinov et al., 2012). Blocks *1–3* are located on a fixed base and blocks *4–11* are found inside the float.

Microprocessor *1* forms signals required for operation. The signals of charge frequency and synchronization are sent to the input of mixer *2*. The output of mixer *2* is connected to reducing transformer *3*. The secondary coil of the power supply transformer *4* and

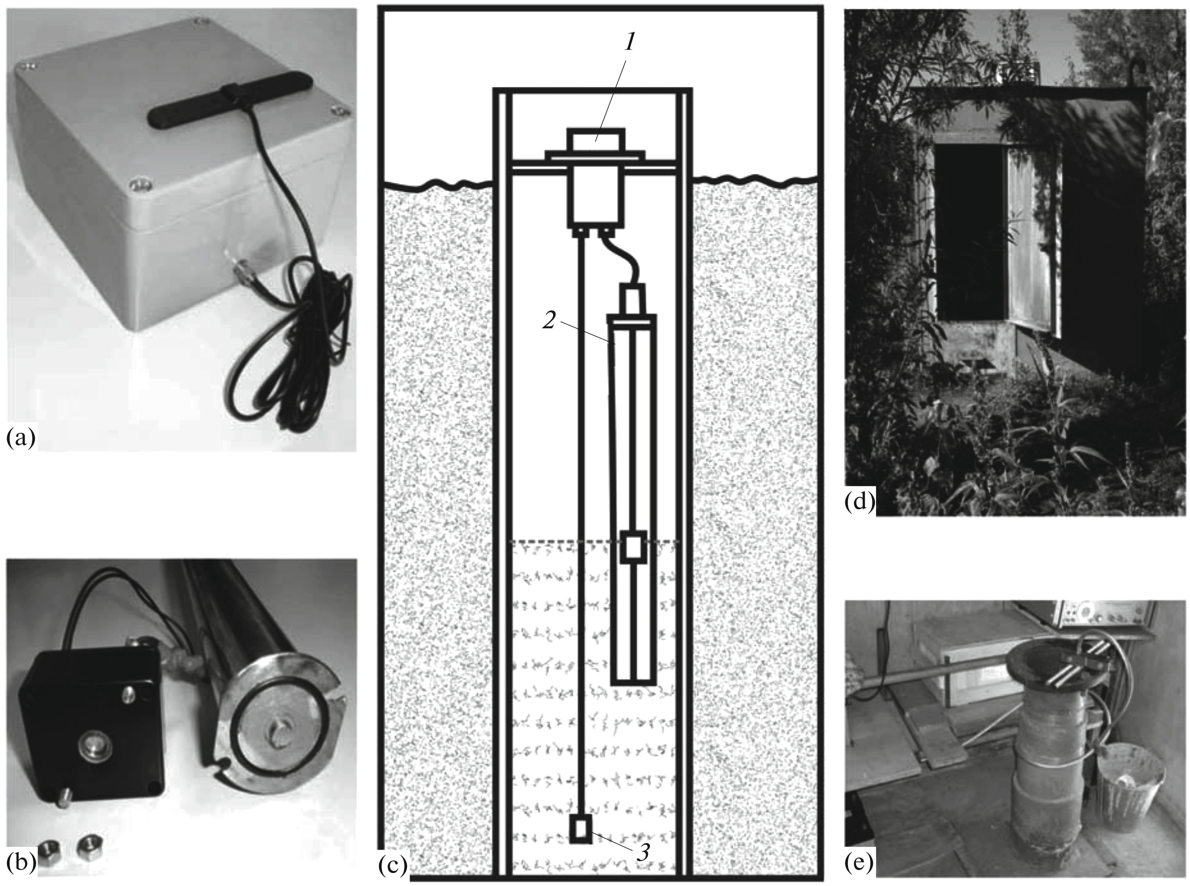

Fig. 2. Components of the Kedr-DM-U measurement system and the scheme of its installation in the well: (a) the BSI 300 registration unit with the GSM aerial connection; (b) the ultrasonic level indicator with the converter; (c) scheme of equipment installation in the well: (*1*) BSI 300 is the data collection unit, including the sensors of atmospheric pressure and air temperature; (*2*) the ultrasonic water level sensor; (*3*) the downhole probe equipped with the sensors of temperature and electrical conductivity of water; (d) the concrete protective structure above the well head; and (e) the head of well E-1.

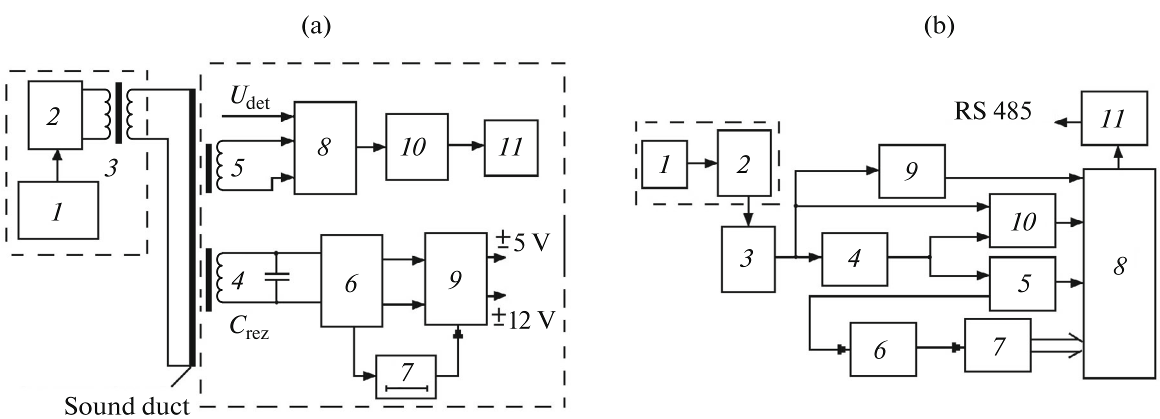

Fig. 3. Flowchart of the well level meter according to (Kalinov et al., 2012): for (a) acoustic emitter and (b) reception of acoustic signals (described in the text).

capacitor C_{res} form a resonance circuit to generate high stress at the output of stress detector *6*. Storage capacitors of unit 6 are charged with current of 16 kHz for 20 ms. The microprocessor generates a synchronization pulse (SP) after some time has passed after a video pulse of the charge frequency ended (Fig. 3). When the signal of charge determined by a rated delay terminated, scheme *7* (Fig. 3a) produces a strobe pulse with duration of 0.1 ms. During its action, unit *9* supplies power to double phase sync pulse detector *8* and unit *10* that forms an electric pulse for piezoceramics excitation *11*. Phase detector *8* registers the first passage of SP stress through a zero level. In this case, the moment of onset of acoustic pulse formation does not depend on the SP amplitude and parameters of a primary coal. The structure and operation of the phase detector are presented in (Kalinov et al., 2009). The electronic circuit of the float, including the transformers of power supply and synchronization, is located on the circuit board with a diameter of 31 mm and a weight of 7.5 g.

The basic factors that influence the level indicator operation are accuracy of registration of the moment of USP arrival and measuring the time of its propagation. Figure 3b presents the functional scheme for the unit of reception and measuring the time of USP arrival. When the acoustic emitter (the float) moves along the wave-guide, the amplitude and form of a leading edge of an acoustic signal change considerably. A phase way of USP registration was implemented in Kedr-A2-U and Kedr-DM-U level indicators, it is similar to SP registration by the emitting float (Kalinov et al., 2009). The SP triggering the USP generator in the float is the onset of measuring the time of USP propagation from the emitter to the receiver. The USP formed by the emitter travels along the waveguide rod and enters peizoreciever *1* (Fig. 3b) and then goes to the input of low-noise amplifier *2*. Elements *1* and *2* are structurally combined and mounted on the edge of the waveguide. Then the signal goes through the second order high-pass filter *3*, amplifier *4*, and amplitude clipper *5*. Flow charts *6* show phase reception of the first half-wave of the pulse. A pulse is formed at the output of flow chart *6* and is digitized by counter *7*. Microprocessor *8* reads from the counter.

After the termination of the measuring pulse, the microprocessor calculates the distance from the emitter to the converter. During the flow chart operation, the signal-to-noise ratio is taken into account (Kalinov et al., 2009). This is done with noise detector *9* and peak detector *10*. The data are transmitted to the microprocessor in the data collection unit via the communication line through built-in interface RS 485 (*11*).

The accuracy of measuring the water level is influenced by the temperature, linear expansion of a metal waveguide, drift of the quartz generator frequency, etc. Noises are eliminated by the method of measuring the level with built-in automatic calibration (Kalinov et al., 2000, 2012).

The ultrasonic well level indicator has the following metrological characteristics: the range of level measurements is up to 3 m, the resolving power of the level gage is 0.1 mm, the major level measurement error is 0.5%, the operating temperature range is –0 to +80°C, the size is 51 × 3180 mm, and the weight equals 3.5 kg.

Downhole probe (Kalinov et al., 2000, 2012). The variations in temperature and electrical conductivity of water measured in a bore of a piezometer well characterize the physicochemical state of ground water. They are measured by a downhole measurement probe that is mounted in a wellbore at a depth range of 10–200 m from the ground surface. In well YuZ-5, the probe is located at a depth of 87 m beneath the head, while that in well E-1 is at a depth of 20 m.

Figure 4 displays (a) the functional scheme of the probe and (b) the structure of electrical conductivity sensor (Kalinov et al., 2012; Lugumanov and Ametshin, 2003).

Platinum resistance temperature detector (Platinum RTD 1000) (*1*) connected to AD converter (*2*) is used as a temperature sensor (Fig. 4a). A 16-bit low-noise sigma-delta converter with AD7788 differential input is used as an AD converter. The device is controlled by built-in microprocessor *3* using the SPI-interface facilities. The temperature is determined by the microprocessor according to a special algorithm with an error no greater than 0.5%.

The electrical conductivity sensor is based on the induction way and represents a system of two coaxially-located toroidal inductor coils (*4* and *5*, Fig. 4b) covered with a common coupling loop in the form of elements of the housing of sensor *10* and the liquid conductor of the controlled water medium. To increase electric sensitivity and to decrease electric noises caused by inductive and capacity couplings, the receiver coil is located in the unclosed screen. Generator *6* supplies alternate voltage with 10 V amplitude to emitting coil *5*. The electromagnetic field produced by eddy currents excites an electromotive force in the receiving coil 4 with a value proportional to electrical conductivity of liquid into which the sensor is submerged. The electromotive force goes from the coil to amplifier *7*, detector *8*, and is received by the microprocessor through AD converter *9*. The scheme forms a constant voltage that is directly proportional to electrical conductivity in the range from 10 mV to 3.3 V. In fact, the conductivity sensor has no electrodes nor an electric contact with liquid, which makes it possible to use it under field conditions and at a great depth. The digitized values of the temperature and conductivity are sent to the data collection unit upon request.

Data collection unit. The central node of the measuring system is a data collection unit (BSI) that represents a specialized unit for data registration (logger) located on the surface above the head of the well

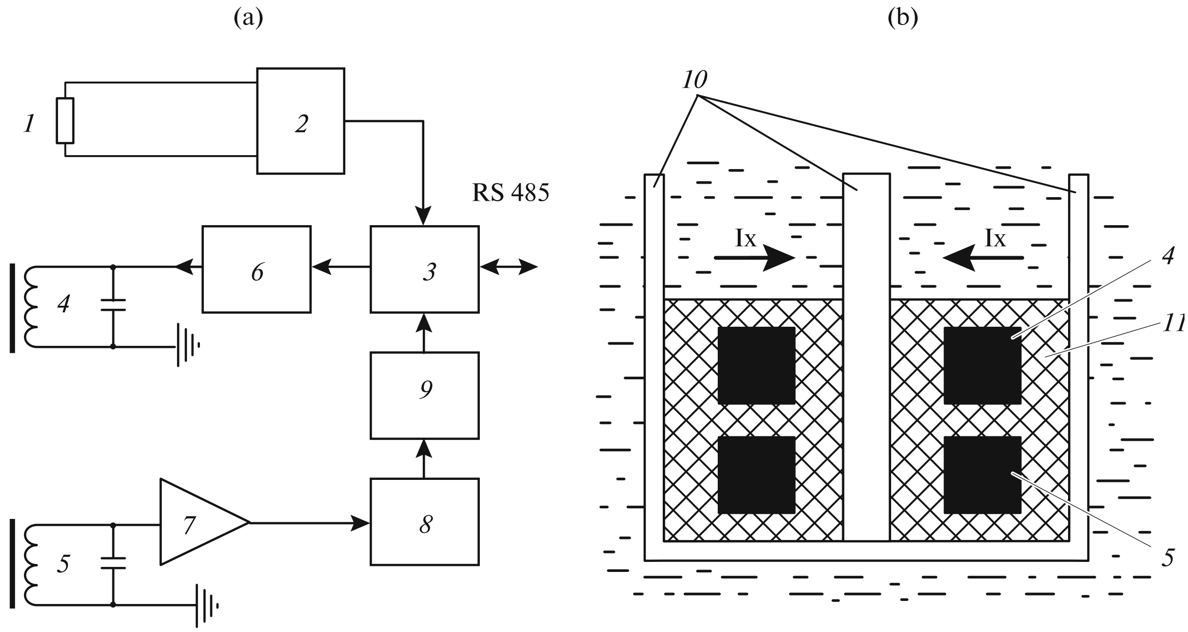

Fig. 4. Downhole probe: (a) flowchart and (b) the structure of the electrical conductivity sensor (described in the text).

(Figs. 2a, 2c). The program control of the logger and the specialized sensors is performed by AVR-type ATMEGA128 microprocessors.

In the initial state, the BSI microprocessor is always in the sleep mode and consumes no more than 70 μA from the +12 V source. The processor is activated under the impact of signals from the command buttons of the remote indicator or by minute impulses of the internal clock. The logger scans the measuring sensors, records the results to the data storage, performs communication sessions, and passes to the lower power mode. The level indicator and the sensors of electrical conductivity and air temperature transmit the information via a special cable (RS 485 interface) to the BSI processor. The air temperature and atmospheric pressure are measured by the sensors mounted on the BSI board and connected to its microprocessor. All sensors can be scanned at a specified periodicity from 5 min to 1 h.

The BSI microprocessor controls the power source voltage and absorbed currents in the measurement channels by the built-in AD converters. The BSI minimizes power consumption by all devices and provides short-circuit protection in the measurement channels. At KB GS RAS, the information from the Kedr-DM measurement systems is transmitted via the mobile communication channels. The modem operation is controlled by the microprocessor with RS 232 interface (UART–RS 232 converter). TC65 modems are used for mobile communication (Terminal, Siemens). Their operating range is GSM 850/900/1800/1900 MHz. The packet data transmission is realized by the modem with built-in GPRS features. Information is transmitted every hour.

RESULTS OF MONITORING

Using the described technical facilities, we started our observations on well YuZ-5 on September 23, 2010 and on well E-1, on September 15, 2011. The interval for measuring the parameters was 5 min; the data were transmitted to the Kamchatka Branch, Geophysical Survey, Russian Academy of Sciences, every hour via the mobile communication channels.

The procedure for processing the data of level-indicator observations to identify the variations in the water level related to the influence of seismicity (hydrogeoseismic variations) is described in (Kopylova at al., 2007) and in other publications by the authors (see http://emsd.ru/lgi/result/hydro). The data were processed daily, which allowed us to detect hydrogeoseismic variations in the parameters of the ground water regime in near real time mode.

In 2013, Kamchatka was striken by a series of strong earthquakes with $M \geq 6$ (*Sil'nye*..., 2014). The largest events were the earthquake of February 28, $M_w = 6.8$, in the sea water area of the Pacific Ocean and the mantle earthquake with $M_w = 8.3$ on May 24 in the Sea of Okhotsk (Fig. 1, table 1). As a result of these earthquakes, various changes in the level and physicochemical parameters of ground waters were recorded in near real time mode (*Sil'nye*..., 2014).

Figure 5 presents the changes in the water level, temperature, and electrical conductivity in well YuZ-6 in January–July, 2013, including short-time hydrogeoseismic variations in the water level (Figs. 5b, 5c) that were caused by the strong earthquakes (Table 1) and were recorded using the above measurement system.

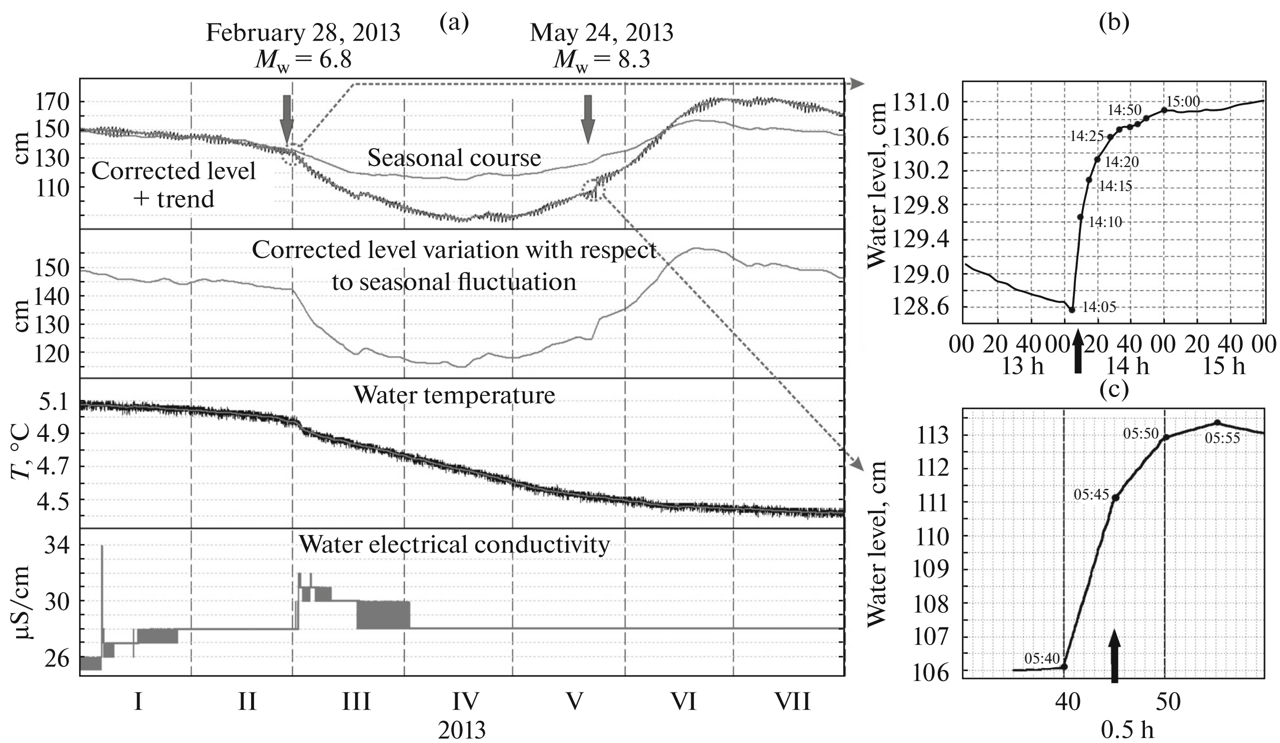

Fig. 5. Variations in water level, temperature, and electrical conductivity for well YuZ-5 from January 1 until August 1, 2013, including co- and postseismic variations caused by the earthquakes on February 28 and May 24, 2013 (shown by arrows) (a); the detailed data on 5-min observations during the onset of seismic waves from the earthquake of February 28, 2013 (b), and the Sea of Okhotsk earthquake of May 24, 2013 (c) .

After the onset of seismic waves from the earthquake of February 28, the level was increasing with amplitude of 2.2 cm for 45 min (Fig. 5b). After the earthquake of May 24, the level was rising with amplitude of 7.3 cm for 20 min (Fig. 5c). These effects could have been caused by the superposition of coseismic jumps of a level increase due to volumetric compression of water-saturated rocks during the formation of ruptures in the earthquake foci and short-time pulses of an increasing pressure in the "well—water-saturated rock" system under seismic wave passage (*Sil'nye*..., 2014).

After the earthquake of February 28, the average hourly changes in the water level showed its intense decrease (Fig. 5a) that occurred until the middle of April 2013. The amplitude of a level decrease was 35 cm for 1.5 months. We note that the effect of a postseismic decrease in the water level was observed earlier in well YuZ-5 only once after the Kronotsk earthquake of December 5, 1997, $M_W = 7.8$. In the case of the Kronotsk earthquake, the level was decreasing with amplitude of nearly 1 m for 3 months (Kopylova, 2006a).

After the earthquake of May 24, the water level was rising (Fig. 5a) until the end of June. The amplitude of the level rise was 24 cm.

The average hourly changes in the water level less the impact of the atmospheric pressure, earth tides, and seasonal variations (Fig. 5a) did not show any anomalies over the period of 1 day to 10 days before the both earthquakes. This indicates the absence of meaningful manifestations of the processes of preparation of these seismic events in the water level changes in well YuZ-5 over a period of 1 day to the first months before the earthquakes of February 28 and May 24, 2013.

Figure 5a also presents the changes in the water temperature and electrical conductivity in the well YuZ-5. After the earthquake of February 28, 2013, the water temperature noticeably decreased with amplitude of 0.6°C and the electrical conductivity increased by 4 μS/cm. Such changes in the physicochemical parameters of ground water can be referred to postseismic variations in the mode of this well. A sharp rise in the electrical conductivity of water with an amplitude of 6 μS/cm was registered on January 7 approximately 8 weeks before the earthquake (Fig. 5a). The possible importance of this effect for the earthquake prediction can be estimated by the results of the further observations.

In well E-1 before the earthquake of February 28, 2013, the hydrogeodynamic precursor manifested itself from January 16 until February 27 (Fig. 6). The hydrogeodynamic precursor in the form of a water level decrease at an increased rate in well E-1 was ear-

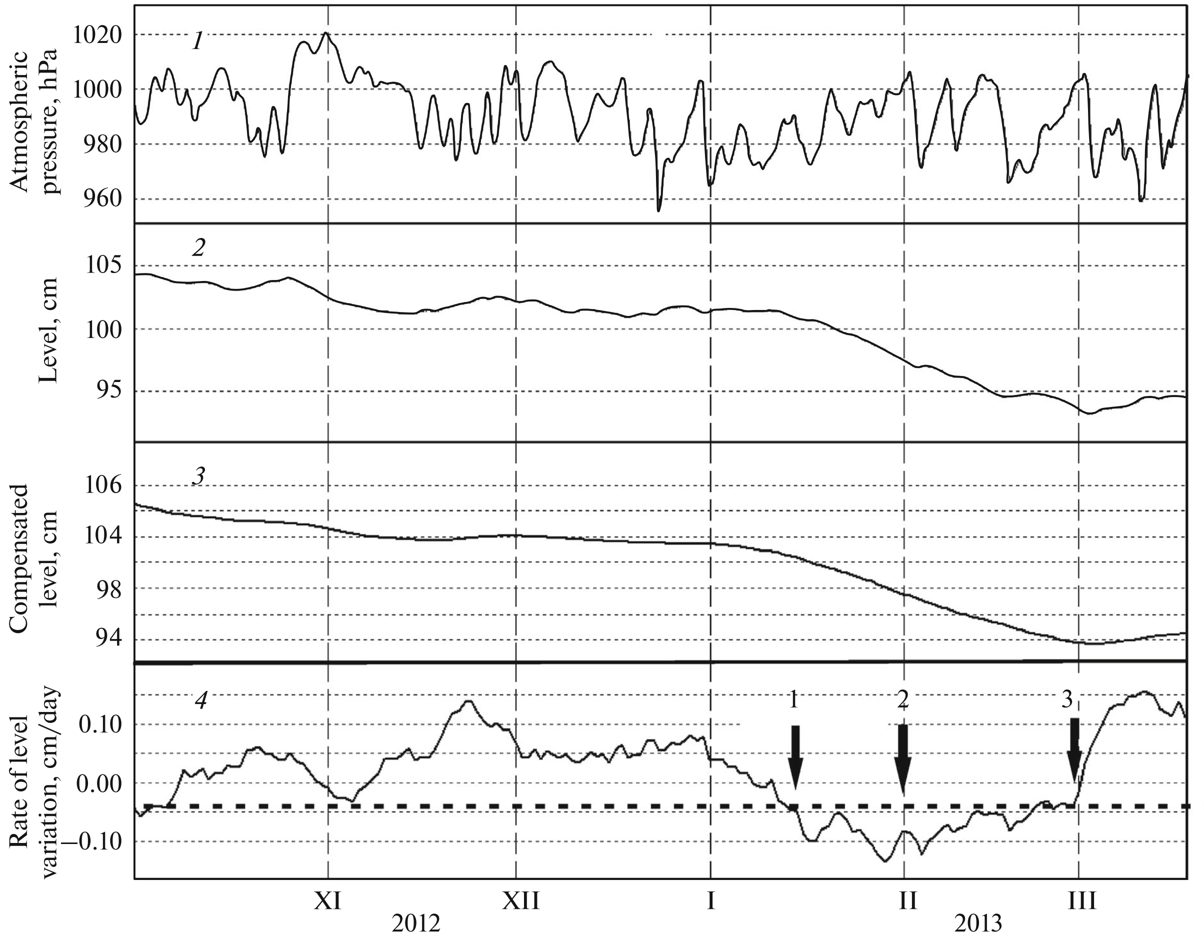

Fig. 6. Water level variations in well E-1 from October 1, 2012, until March 18, 2013: (*1*, *2*) 5-min registration data for atmospheric pressure and water level; (*3*) daily-average variations in the water level with compensated bar variations; (*4*) daily rate of a water level variation with respect to the rate of a descending trend. The arrows in the plot designate (1) January 16, 2013, the onset of the hydrogeodynamic precursor manifestation; (2) February 1, 2013, the prediction summary was sent to Kamchatka Branch, Geophysical Survey, Russian Academy of Sciences; (3) February 28, 2013, is the earthquake. Horizontal dashed line denotes a threshold value for the daily rate of level variations.

lier described in (Kopylova, 2001; Kopylova and Boldina, 2012; et al.). The special features of this precursor are (1) its relatively regular recurrence before the earthquakes with $M \geq 5.0$ at a distance of ≤350 km (over 70% of cases); thus, it can be used for predicting strong local earthquakes; (2) the increase in the connection between the precursor and the earthquakes as their magnitude rises (Kopylova, 2001), which indicates that the precursor manifests itself even more regularly before stronger seismic events.

This kind of precursor has been used since 2002 to assess the hazard of occurrence of strong events around the city of Petropavlovsk-Kamchatsky based on the current data of level indicator observations on well E-1, and the prediction results are provided to the Kamchatka Branch of Russian Expert Council on Earthquake Prediction, Assessment of Seismic Hazard and Risk (KB REC). On February 1, 2013, G.N. Kopylova prepared a medium-range prediction based on this precursor about an increased probability of strong earthquake occurrence on Kamchatka and passed it on to KB REC (Fig. 6). The prediction summary of February 1, 2013, stated that there was an increased probability during 1–2 months for occurrence of an earthquake with $M \geq 5.0$ at a distance of up to 350 km to the well. The summary also contained the assessments of prediction reliability for earthquakes with different magnitudes that were based on the results of the retrospective analysis of the manifestations of the hydrogeodynamic precursor for the period of long-term observations (Kopylova and Sizova, 2012): "the probability of an event with $M \geq 5.0$ $P = 0.45$, prediction efficiency of the precursor $I = 1.4$; the probability of an event with $M \geq 5.9$ $P = 0.73$, prediction efficiency of the precursor $I = 2.2$." In this summary, probability of an event P means a ratio of the number of earthquakes in the indicated range of magnitudes that occurred at a distance of up to 350 km from the well and were preceded by the appearance of the precursor to the total number of such events. The value of prediction efficiency I was determined according to (Gusev, 1974), showing how much the use of this particular precursor improves the prediction compared to random guessing.

The earthquake with $M_W = 6.8$ that occurred on February 28 at a distance of 290 km from the well matched the prediction of February 1 with respect to magnitude, time, and location. Therefore, the prediction presented to KB REC on February 1, 2013, is successful according to the author's opinion and the opinion of KB REC (*Sil'nye*..., 2014, p. 152).

According to the observations of the water level variations in well E-1, the prediction of the earthquake presented to KB REC on February 1, 2013, is also probabilistic, since it was accompanied by the estimates of its probable implementation with respect to events with different magnitude values. This was possible after the data on the manifestation of a hydrogeodynamic precursor had been systematized compared to the earthquakes that occurred in well E-1 over the period of long-term observations (1987–2012). Thus, we prepared its parametric description (Kopylova, 2001; Kopylova and Sizova, 2012).

After the earthquake of February 28, 2013, a postseismic increase and a subsequent recovery of water level were recorded in well E-1 for 1.5 months. For 2 days after the earthquake, the variations in electrical conductivity showed its slight increase with amplitude of 2 μS/cm. Retrospectively, we established an increase in water electrical conductivity by 2 μS/cm on January 12, 2013.

The variations in the water level in well E-1 during the earthquake on February 28 were the following: its decrease at an increased rate within 44 days before the earthquake and its increase with amplitude of approximately 2 cm after the earthquake (Fig. 6) is typical for the periods of occurrence of strong ($M \geq 6.6$) local earthquakes at distances of up to first few hundred kilometers (Kopylova, 2001, 2010). A consecutive manifestation of the hydrogeodynamic precursor, which was changed to a postseismic increase after the earthquake, was recorded in the water level variations in well E-1. This is consistent with the earlier-established pattern of a water level change in this well during such earthquakes.

Using a downhole probe and based on the registration data of physicochemical parameters of ground water in well E-1, we detected a weak increase in the water electrical conductivity with amplitude of 2 μS/cm for 2 days after the earthquake (a postseismic effect). The changes in the water temperature did not show hydrogeoseismic variations.

CONCLUSIONS

Developed at KB GS RAS, the system of observations on wells using the Kedr-DM hardware system (*Kedr-DM*..., 2007) produced by OOO Polynom, the city of Khabarovsk, makes it possible to detect hydrogeoseismic variations in the changes of a level and physicochemical parameters of ground water in near real time mode. Such data allowed us to thoroughly study the registered hydrogeoseismic variations in the changes of physicochemical parameters of ground water to estimate the influence of seismicity on the state of ground water, including the processes of preparation of strong earthquakes. Methodology of studying hydrogeoseismic variations in the parameters of ground water should comprise their systematization and typification as compared to the data on earthquakes that caused them with respect to local hydrogeological conditions.

The experience of observing hydrogeoseismic variations in the water level, temperature, and electrical conductivity using the Kedr-DM hardware system in two piezometric wells during strong earthquakes in 2013 showed reliability of all its elements and high registration accuracy of the water level with an ultrasonic well level indicator.

Along with that, a downhole probe, a part of the equipment (Fig. 2c), should be improved by adding higher resolving power to the sensor of water electrical conductivity. Currently, its resolving power is 1 μS/cm, which is insufficient for confident identification of hydrogeoseismic variations in the changes of ground water electrical conductivity. During the registration of the water level variations, the measurements should be taken with a frequency at least 1–10 Hz, especially under seismic wave passage, as is practiced abroad (in Japan, United States, China, Israel, and other countries) in performing similar observations (Wang and Manga, 2010).

The changes in the parameters of ground water in well YuZ-5 (Fig. 5) showed the hydrogeoseismic variations caused by the action of seismic waves from the earthquake of February 28, 2013, including the decrease in the water level and temperature and the increase in electrical conductivity with maximum amplitude of 4 μS/cm. The postseismic effects were developed for 1–2 months. Eight weeks before the earthquake, the water electrical conductivity had risen by 6 μS/cm.

The observation data obtained using the level indicator in well E-1 allowed us to develop a successful prediction of the earthquake of February 28, 2013, $M_W = 6.8$, four weeks before it occurred. The prediction was accompanied by the probabilistic assessment of its implementation based on the retrospective study (according to the data of long-term observations) of the hydrogeodynamic precursor in the changes of a water level due to the earthquakes recorded and its parametric description.

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