Kamchatka Branch of the Geophysical Survey of the Russian Academy of Sciences (KB GS RAS)

Groundwater Pressure Changes Due to Magmatic Activation: Case Study of The E-1 Well, Kamchatka Peninsula, Russia

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Petropavlovsk-Kamchatsky, GVW2020

The city of Petropavlovsk-Kamchatsky is located near the active volcanoes Koryaksky (left) and Avacha (on right)

Foto N.I. Seliverstov

Explosive-effusive eruption of volcano Avacha, January, 1991

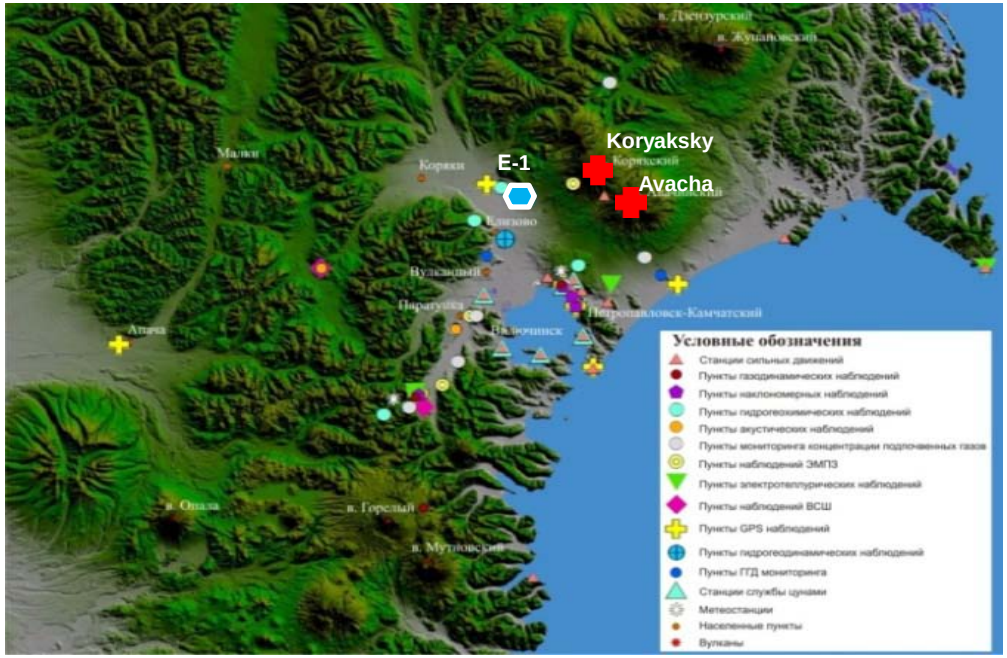
https://maxfux.livejournal.com/372479.html

Hydrothermal-magmatic eruption of volcano Koryaksky, December 2008 - 2009

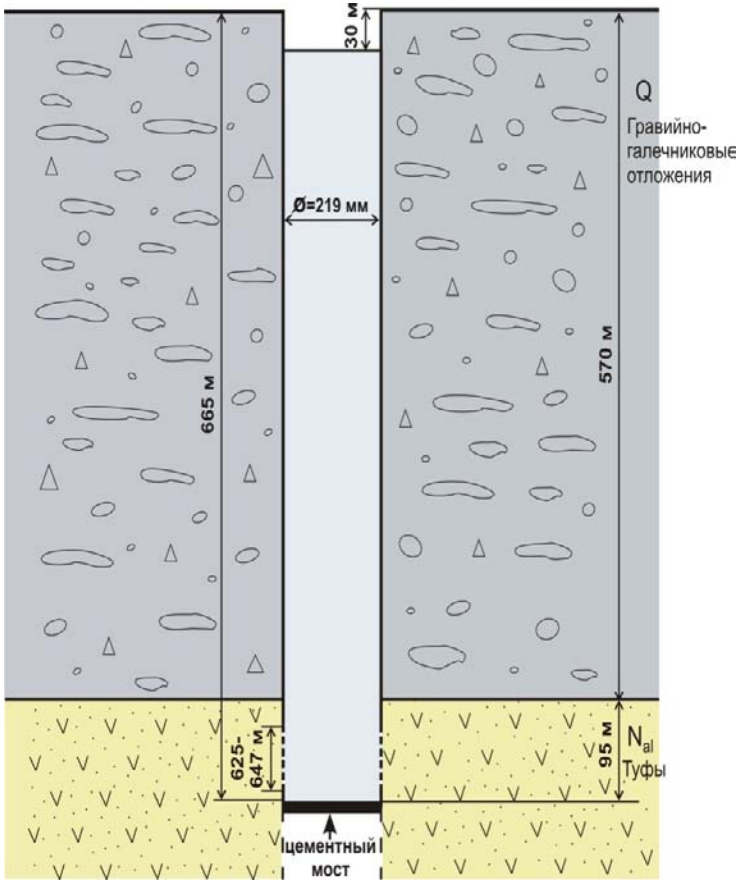
Volcano Koryakskiy activity in 2009-2011

Kopylova, Boldina, 2012

Location of the well E-1 and active volcanoes



Well structure



Equipment for measuring water level: KEDR DM-U (LLC "Polynom", Russia)

Registration interval - 5 min.
Data transmission - 1 time per hour
Data processing is performed daily:
http://www.emsd.ru/lgi/observations

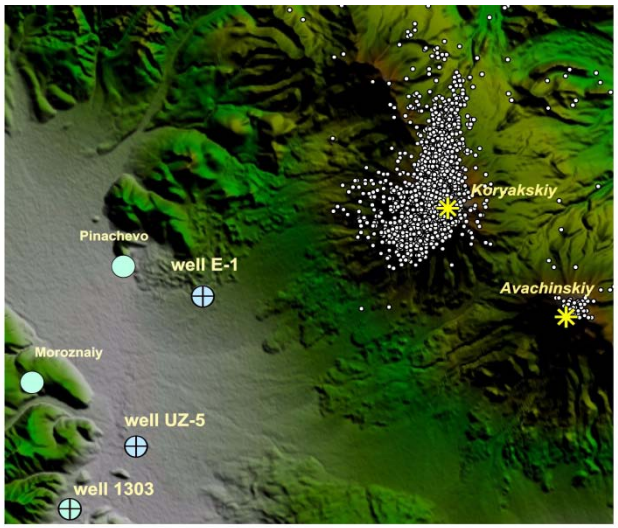
Elastic and filtration parameters of water-bearing rocks ***(Kopylova, Boldina, 2012)***

Barometric efficiency, E_b cm/gPa	Tidal sensi-tivity, A_V m/10^{-7}	Compres-sibility, β Па$^{-1}$·10^{-11}	Shear modulus, G Pa·10^{10}	Skempton's coefficient, B	Porosity, ϕ	Storage coefficient, S	Transmis-siviity, T, m^2/day	Hydraulic conductivity, $k=T/d$, m/c	Hydraulic diffusivity, $a=k/S_S$ m^2/c
0.01	**0.015**	**7.59**	**0.79**	**0.044-0.17**	**0.05**	**5.8·10^{-5}**	**0.005**	**3·10^{-9}**	**0.001**

Mineralization of water M=1.5 g/l. Water chemistry Cl-CO_3/Na
Gas: N_2-CH_4

WATER LEVEL CHANGES IN THE PERIOD OF KORYAKSKY VOLCANO ERUPTION, Dec. 2008-2009 (Kopylova, Boldina, 2012)

Δh=1.22 m, Δp=12 kPa (0.12 bar), $\Delta\varepsilon = -(4.1\cdot10^{-6} - 1.5\cdot10^{-5})$



Region of Koryakskiy volcano and position of the well E-1: 1 - active volcanos; 2 - epicenters of earthquakes in area of volcano Koryakskiy in 2008-2010; 3 - flowing wells; 4 - piezometric wells


10 Jan. 2009, fumarolic activity
foto D.V. Melnikov

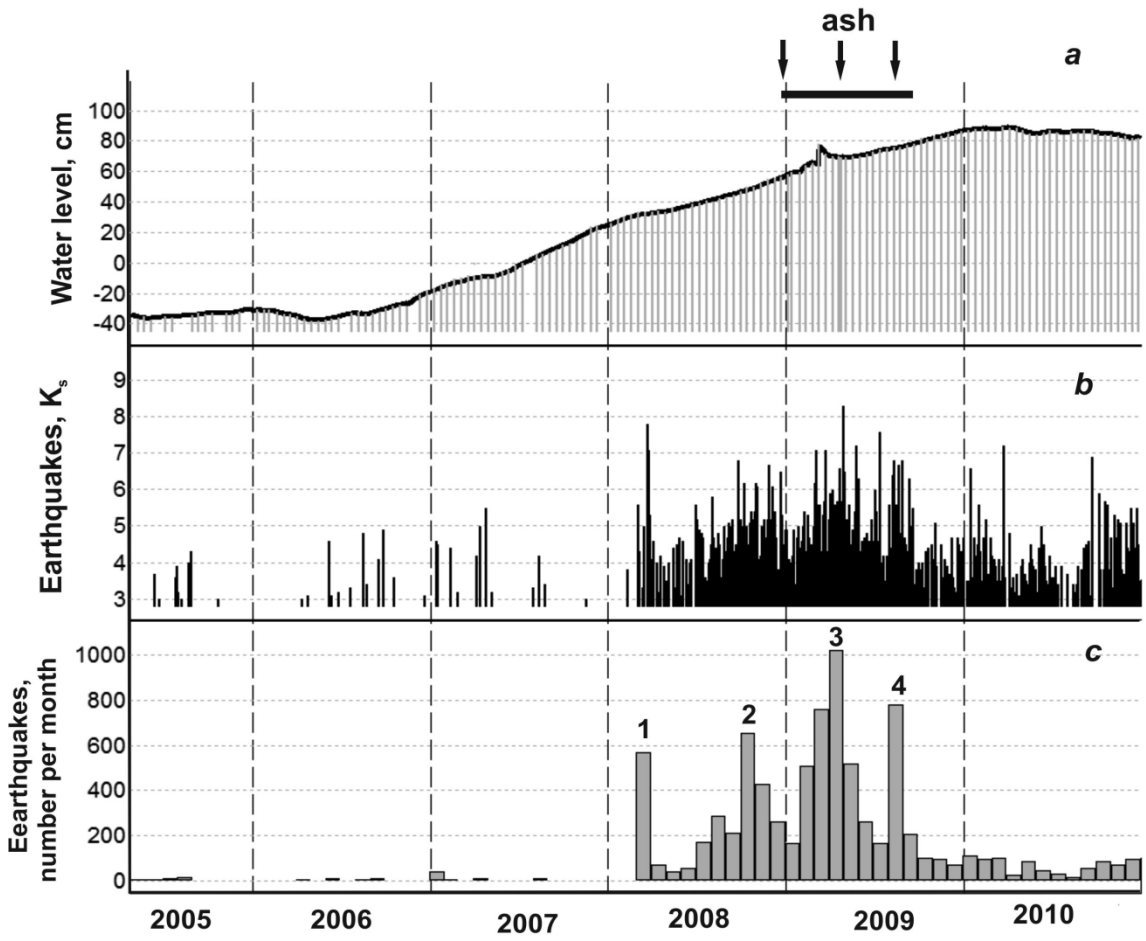

9 Apr. 2009, fumarolic activity, ash
foto S.V. Ushakov


27 Aug. 2009, fumarolic activity, ash
foto O.A. Girina


19 Oct. 2009, fumarolic activity
foto S.V. Ushakov

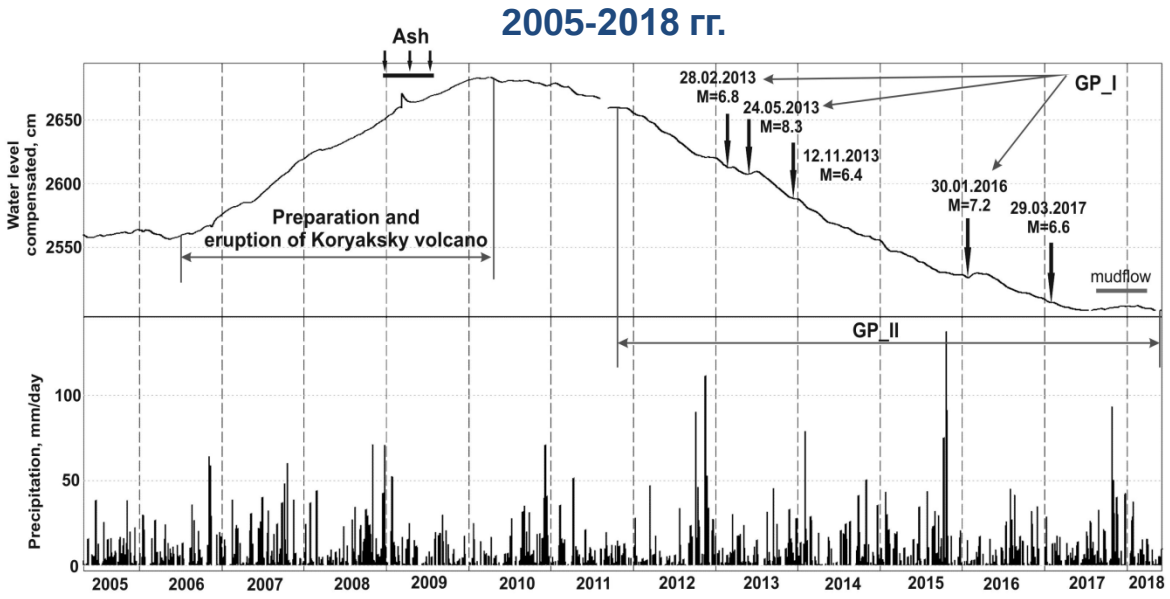

30 Jan. 2011, week fumarolic activity
foto A.A. Nushdaev

Volcano Koryakskiy activity in 2009-2011



An increase in the water level from mid-2006 to 2009 is considered as a growth of groundwater pressure due to volumetric compression of water-bearing rocks during the preparation, seismic activation and phreato-magmatic eruption of Koryaksky volcano.

WATER LEVEL CHANGES IN THE WELL E-1, 1987-2018, KB GS RAS:
two cases of long-term increases in groundwater pressure

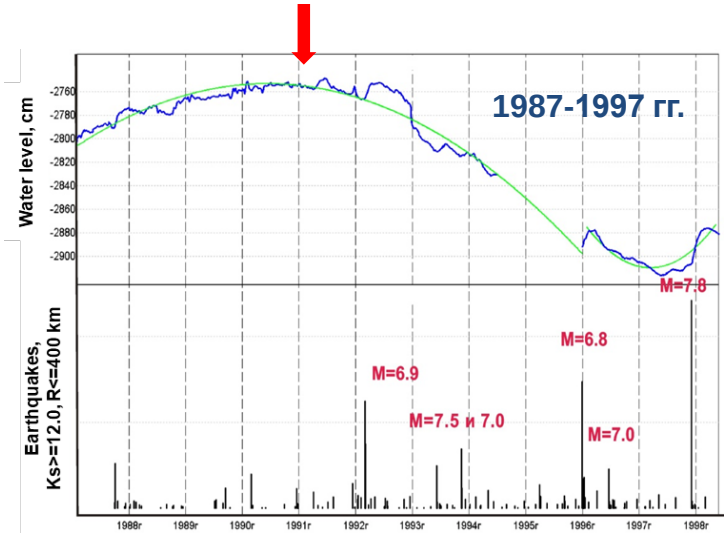


The eruptions of the Avacha volcano in February 1945. (photo on the left © V.P. Kuznetsov) and in January 1991 (photo on the right © V. Podtabachny).

Parameters of long rise in water level before eruptions

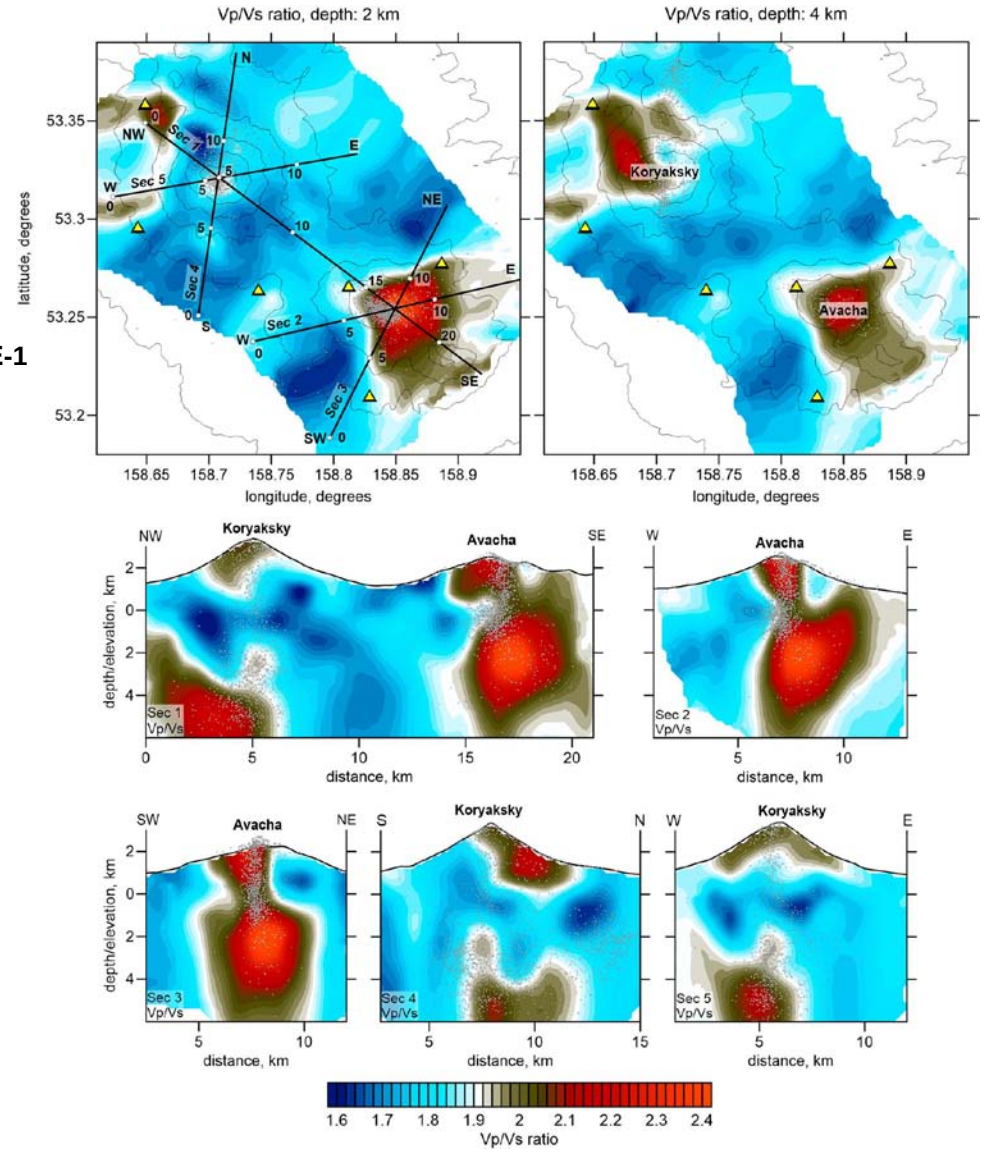
Manifestation of the level increase; years, months (days)	Amplitude of level rise, m / average rate of rise, cm/day	Increasing water pressure, bar	Volumetric compression of water-bearing rocks $\Delta\varepsilon$, 10^{-6} / rate, day^{-1}
Explosive-effusive eruption of volcano Avacha, January 12-26, 1991			
January 1987 – January 1991, 3 years 1 month (≥1125 days)	≥0,45 / 0,04	≥0,045	≥3,0 / $2,7 \cdot 10^{-9}$
Hydrothermal-magmatic eruption of volcano Koryaksky, December 2008 - 2009			
June 2006 – December 2009, 3 years 6 months (1260 days)	1,22 / 0,10	0,122	8,1 / $6,4 \cdot 10^{-9}$

Avacha volcano eruption



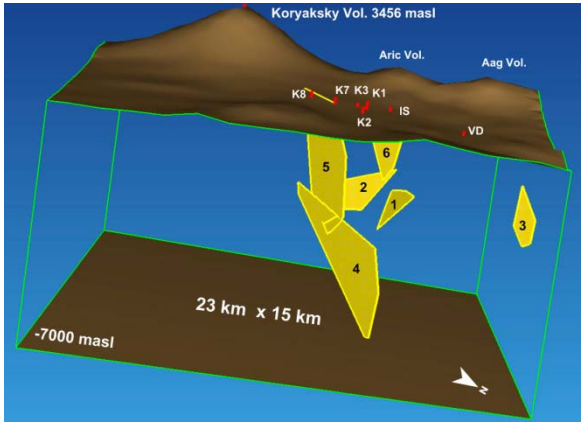
Kopylova (2001), Volcanology and seismology, No2

Possible sources of water-bearing rock compression can be the magma degassing and movement in the magma chambers beneath the Avacha and Koryaksky volcanoes.



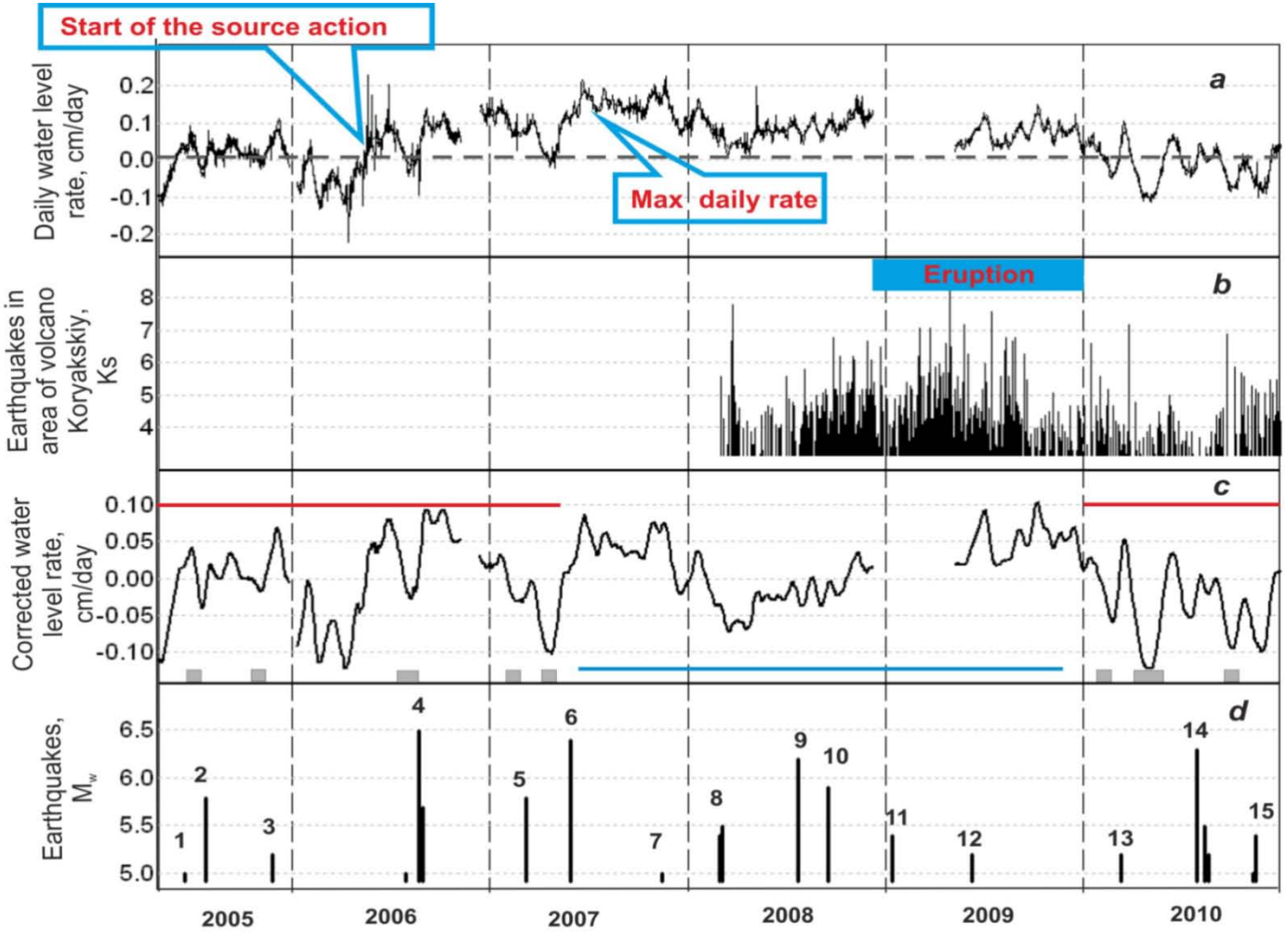
The distributions of the Vp/Vs ratio in two horizontal and five vertical sections. Locations of the sections are shown in the left-hand map. Triangles depict the seismic stations and dots are the events recorded at the sections.

Bushenkova, Koulakov, Senyukov at al. (2019). Tomographic images of magma chambers beneath the Avacha and Koryaksky volcanoes in Kamchatka. *JGR Solid Earth, 124, 9694–9713. https://doi.org/10.1029/2019JB017952)*



Magma injections (dykes) below the northern foothills of Koryaksky volcano during the time period from 2011 to 2019. (Kiryukhin et al., 2020)

Reducing the well E-1 sensitivity to the preparation of strong (M> 5.0) earthquakes when a "compression source" occurred in area of Koryaksky volcano (Kopylova, Boldina, 2012)

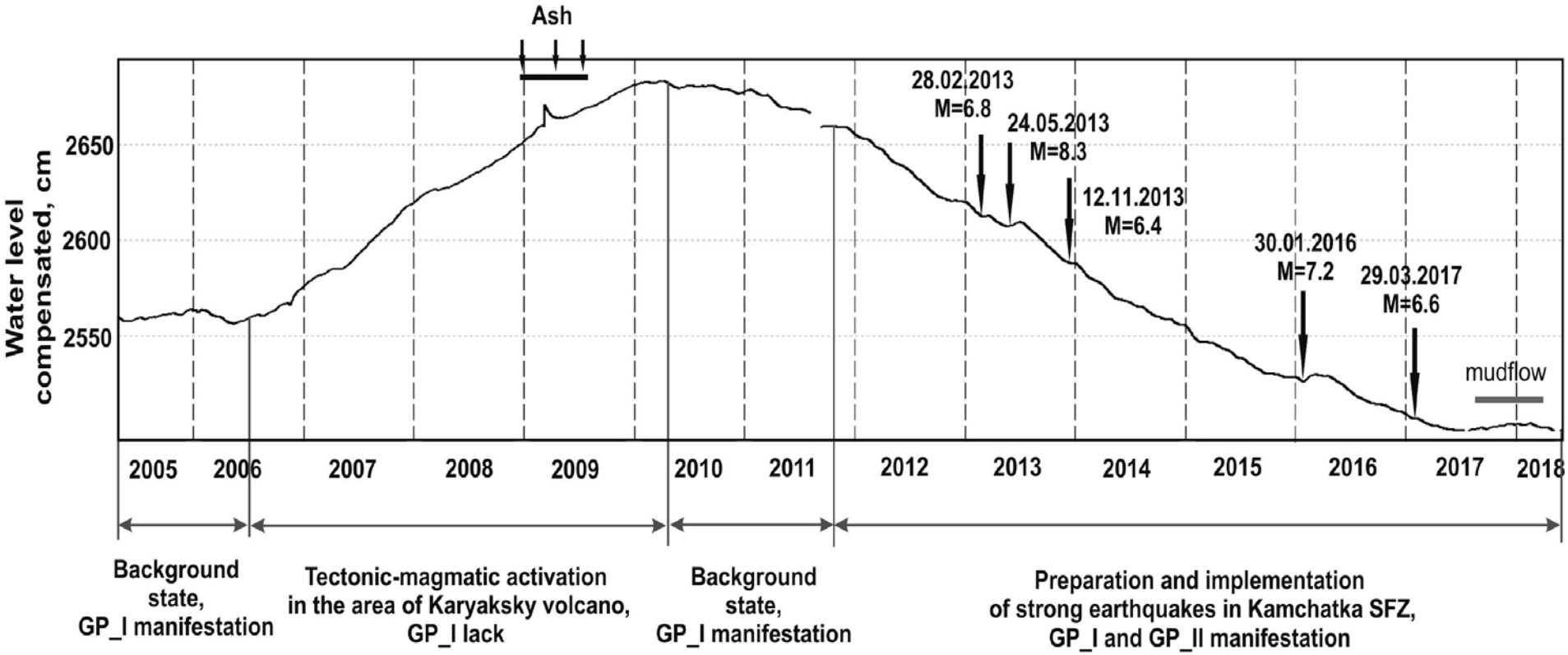


The daily rate of the water level changes (a, c) in comparison with seismicity in the area of Koryaksky volcano (b) and subduction earthquakes, M≥5, d_e≤350 km (d).

Red lines show the manifestation of GP in water-level changes (gray thick lines), blue line - the absence of GP (c).

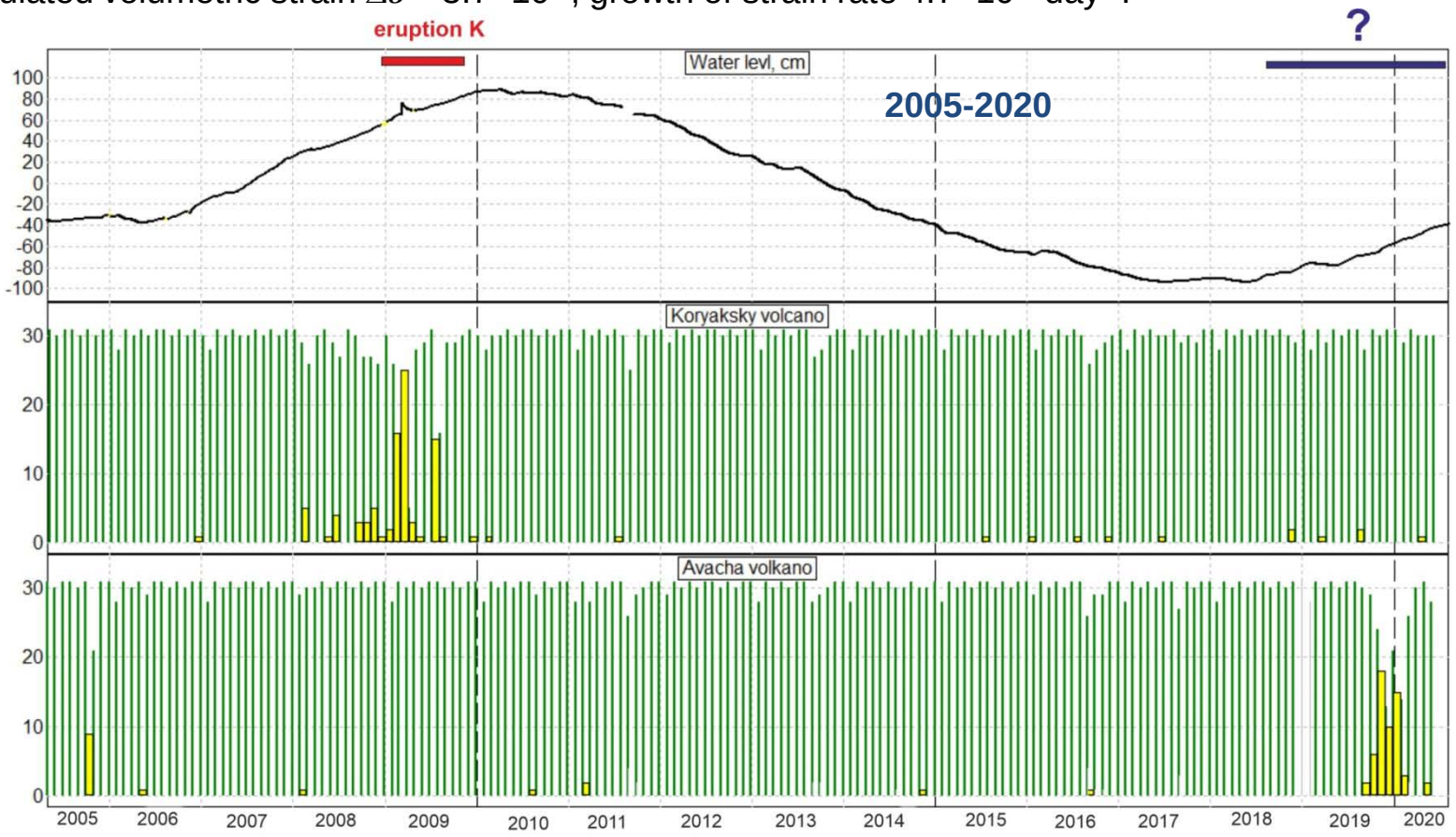
Hypothesis: the absence of the precursor GP in water level changes before subduction earthquakes can be a sign of volcanic activation.

PHASES OF GEODYNAMIC CONDITION OF WATER-BEARING ROCK ACCORDING TO WATER LEVEL CHANGES IN THE WELL E-1 *(Kopylova, Boldina, GVW2018)*



From Jun. 2018 to August 2020 the raising in water level at increased r ate is observed (blue line):

- amplitude of the water-level raising Δh=0.55 m (the average rate is 0.07 cm/day);
- water pressure increase Δp=0.055 bar;
- accumulated volumetric strain $\Delta\varepsilon = 3.7\times10^{-6}$, growth of strain rate 4.7×10^{-9} day^{-1}.

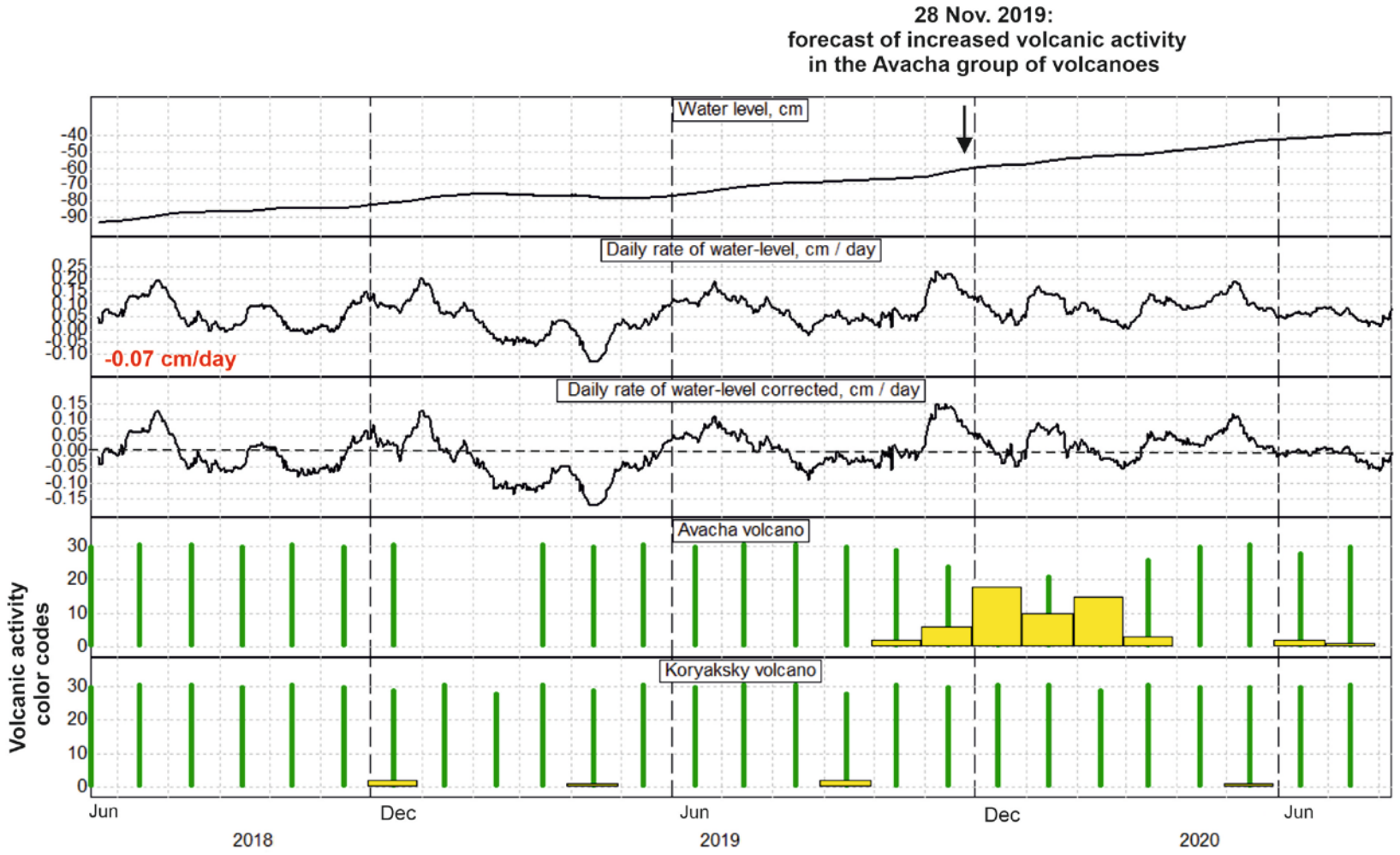


Water level changes are compared with the monitoring of volcanoes Koryaksky and Avacha on the basis of four color codes (http://www.emsd.ru/~ssl/monitoring/main.htm).

The green bars show the number of days in the month when the green color code corresponded to "the volcano is calm“ was assigned.

Yellow bars - the number of days in a month when the yellow color code was displayed, corresponding to weak activation (weak local earthquakes, increased gas emissions, ash, thermal anomalies).

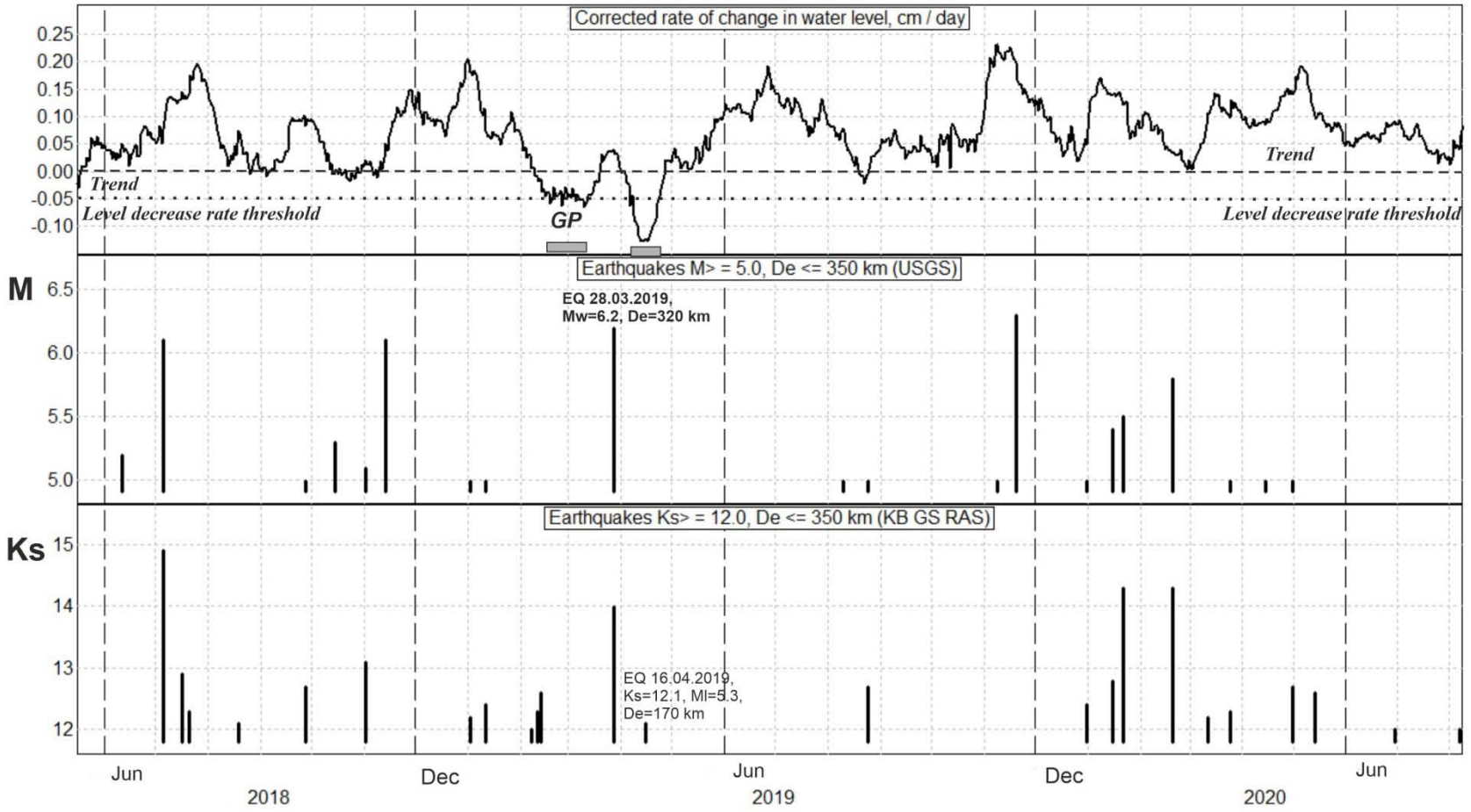
Changes in the rate of water-level rise in Jun. 2018 - August 2020 and forecast of increased volcanic activity in the area of Avacha group of volcanoes



1. *From Nov. 28 to the present, weekly forecasts are given about the possibility of volcanic activation in the area of Avcha group of volcanoes.* ***Will there be an eruption and which volcano - Koryaksky or Avach?***

2. ***Is there a weakening of the well sensitivity to the preparation of subduction earthquakes?***

Precursor GP1 manifestation in water level changes, Jun. 2018 – Avg. 2020



From mid-2019 to the present, the GP has not appeared.

It can be assumed that the sensitivity of the well to the preparation of subduction earthquakes is weakened due to the action of a source of volumetric compression of water-bearing rocks.

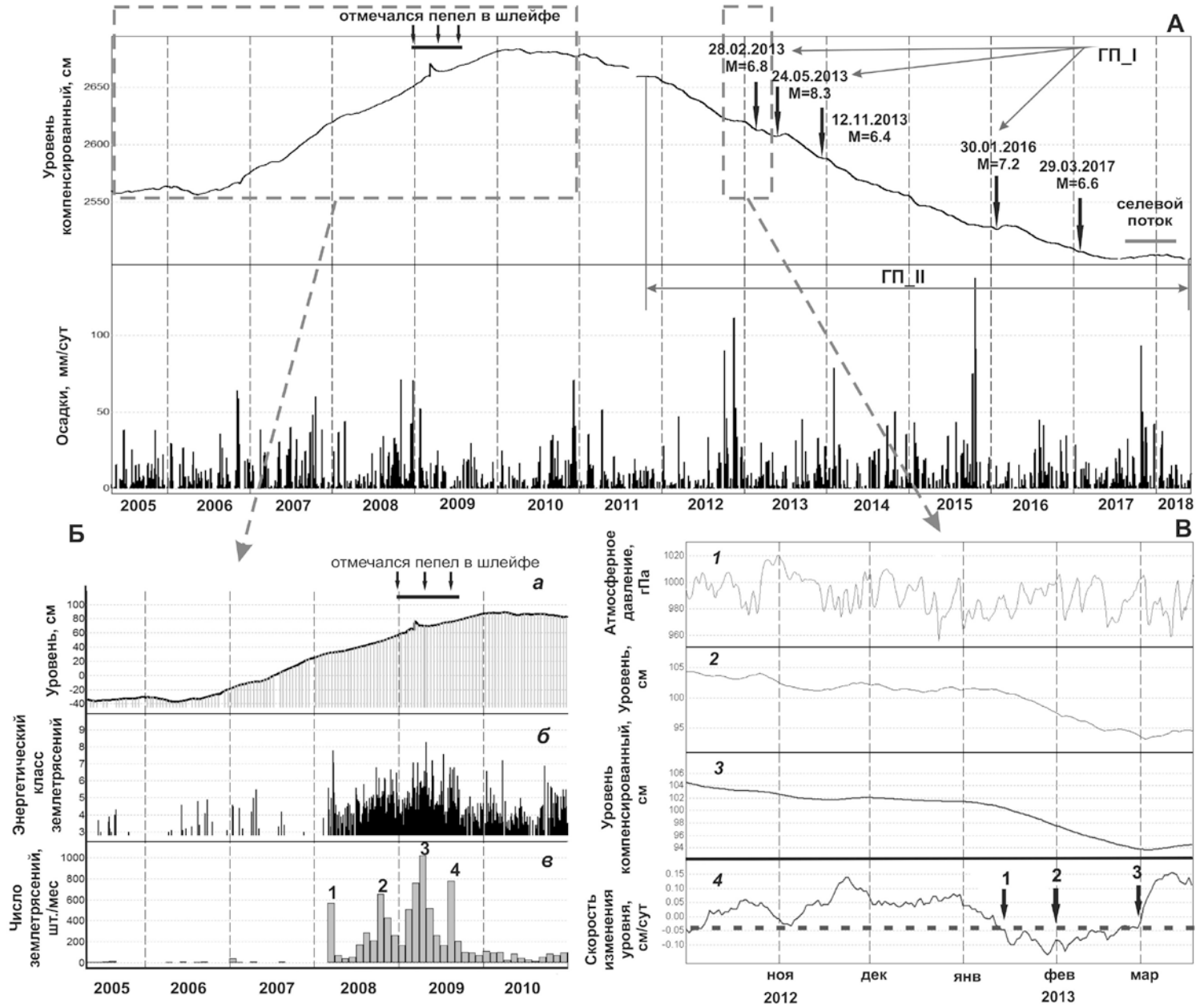
A difficult question: which of the two volcanoes – Koryaksky or Avacha will erupt?

1. **Volcano Koryaksky** has not shown increased activity in recent years. No eruption is expected.

2. **Volcano Avacha**: According to the data of the KB GS RAS *(http://www.emsd.ru/~ssl/monitoring/main.htm)*, in the region of the volcano, increased seismicity and glow at night in the western part of the crater appeared.
In 2012-2016 the temperature of the Western fumarole increased from 370 to 819°C *(Malik et al., 2017).*

Taking into account the data of the KB GS RAS on the development of seismicity, fumarolic activity and water-level data, it can be assumed that the Avacha volcano is the most likely candidate for an eruption in the coming months - the first years.

Continuation of water-level observations in the E-1 well and use the additional predictive signs such as the increase in the rate of water-level raise, a weakening of the well's sensitivity to the preparation of subduction earthquakes and other data will clarify the time of the Avacha volcano eruption.



Kopylova, Boldina, GVW2018

GP1 manifestation

Оценка объемной деформации по данным уровнемерных наблюдений в скважине Е-1

Оценка объемной деформации в районе скважины

Пренебрегая течением жидкости в резервуаре для статически изолированных условиях можно оценить приращение объемной деформации водовмещающих пород (расширение – положительное) из уравнения [*Roeloffs, 1988*]:

$\Delta p = -(2GB/3)[(1+\nu_u)/(1-2\nu_u)]\Delta\varepsilon$, где ν_u – коэфф. Пуассона для недренированных условий (0.3)

$\Delta h = 1.22$ м

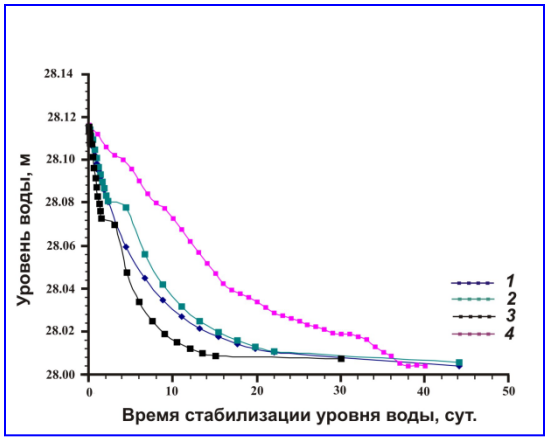
$\Delta\varepsilon = -(\rho g \Delta h)/(2/3GB[(1+\nu_u)/(1-2\nu_u)])$

Оценка модуля сдвига *G* и коэффициента Скемптона *B*

Модуль сдвига и коэффициент Скемптона оценивались по формулам теории пороупругости для статически изолированных условий в системе «скважина–резервуар», ϕ - по аналогии со скв. 1303: $B=(\rho g A_S \beta)/[1+\rho g A_S(\beta-\beta_u)]$ $B=\rho g \beta_u A_V$

$B=(\beta-\beta_u)/[(\beta-\beta_u)+\phi(\beta_f+\beta_u)]$ $G=3/2[(1-2\nu)/\beta(1+\nu)]$

Оценка упругой водоотдачи *S* по результатам моделирования восстановления уровня после спуска датчика АЭ



Стабилизация уровня воды:
1 – расчетная стабилизация уровня при Т=0.005 м²/сут и S=2·10⁻⁵;
2 - расчетная стабилизация уровня при Т=0.005 м²/сут и S=5.8·10⁻⁵, $\beta_f = 4.4\cdot10^{-9}$ Па⁻¹ ;
3 - расчетная стабилизация уровня при Т=0.008 м²/сут и S=4.4·10⁻⁴;
4 – стабилизация уровня по данным 10 минутных экспериментальных замеров.

$S=d[\rho g(\beta+\phi\beta_f)]$,

где β, ϕ - по аналогии со скв. 1303, а $\beta_f = 4.4\cdot10^{-10} \div 4.4\cdot10^{-6}$ Па⁻¹

Оценка деформометрической чувствительности уровня воды

Так как скважина Е1 не реагирует на приливы, то деформометрическая чувствительность A_V, необходимая для определения пороупругих параметров резервуара, была получена из уравнения $\Delta h_{ЮЗ\text{-}5}/A_{VЮЗ\text{-}5} = \Delta h_{E1}/A_{VE1}$ с использованием данных по проявлению гидрогеодинамического предвестника Кроноцкого землетрясения в скважинах ЮЗ-5 и Е1.

Скважина/ открытый ствол, *d*, м	Барометрическая эффективность E_b см/гПа	Приливная чувствительность A_S/A_V м/10^{-7}	Дренированная сжимаемость скелета β Па$^{-1}\cdot10^{-11}$	Модуль сдвига *G* Па$\cdot10^{10}$	Коэффициент Скемптона *B*	Удельная упругая емкость S_S м$^{-1}\cdot10^{-7}$	Пористость ϕ	Величина водоотдачи, $S=S_S d$	Коэффициент водопроводимости *T*, м²/с	Коэффициент фильтрации, $k=T/d$, м/с	Пьезопроводность, $c=k/S_S$, м²/с
Е1/20	0.01	0.010/0.015	7.59	0.79	0.044÷0.17	29.0	0.05	$5.8\cdot10^{-5}$	$6.3\cdot10^{-8}$	$3.2\cdot10^{-9}$	0.001
1303/200	0.43	0.143/0.215	7.37	0.81	0.64	9.81	0.06	$9.8\cdot10^{-5}$	$2.4\cdot10^{-5}$	$2.4\cdot10^{-7}$	0.25

$$\Delta\varepsilon = -(4.1\times10^{-6} \div 1.5\times10^{-5})$$