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Temperature variations related to earthquakes from simultaneous observation at the ground stations and by satellites in Kamchatka area

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Abstract

Air temperature, surface temperature, retrieved from satellite data, and well observations on the Kamchatka peninsula, Far East, Russia were jointly analysed. Air temperature indicates correlation with seismic activity. Satellite observations showed the presence of thermal anomalies on the earth surface in the basin of the Kamchatka river. Thermal anomalies reaction on three strong earthquakes were recorded. Water temperature, outflow and hydrogen ion exponent (pH) changes were observed as a response to seismic events. Joint analysis indicates similarity both satellite and ground observations related to earthquakes. A model of litho–atmo–ionospheric coupling in seismic processes is proposed.

Keywords: Air temperature; Thermal anomaly; Earthquake; Satellite thermal image

1. Introduction

Geochemical observations became an essential part of earthquake research (Roeloffs, 1988). Water temperature and flow rates are considered as one of the main parameters. Historical data analysis also points to air temperature deviation related with earthquakes (Mallet, 1851; Rikitake, 1976). On the other hand, modern satellite methods allow us to retrieve earth's surface temperature quickly and on large areas. Numerous observations of thermal anomalies related with earthquakes from all over the world were reported (Qiang Zuji and Du Le-Tian, 2001; Tramutoli et al., 2001; Tronin et al., 2002). A set of comprehensive geochemical and meteorological observations was carried out in the Kamchatka area. This dataset was expanded with thermal satellite observations.

As a next step of research we would like to relate satellite and ground data, to build a model of thermal anomalies, to reveal the nature of the anomalies and to develop a model of surface instability in litho–atmo–ionospheric coupling in seismic processes. We will mainly pay attention in this paper to relations between water, surface, air temperature and water flow rates variations with seismicity. The urgency of the establishing of this relation was emphasised in the UNESCO initiative—Integrated Global Observing Strategy—Geohazards Theme, where the connection of ground and satellite observations is considered as a key point of strategy (Genderen, 2001).

2. Data

The Kamchatka peninsula locates in Far East, Russia. This region is remarkable for its high seismicity, volcanic activity, geothermal fields, geysers, complex relief and bad weather conditions for satellite observations (Fig. 1).

Hydrogeochemical and ancillary observations for earthquake research in Kamchatka had been initiated in 1977 and continue till now. A ground test site is located in

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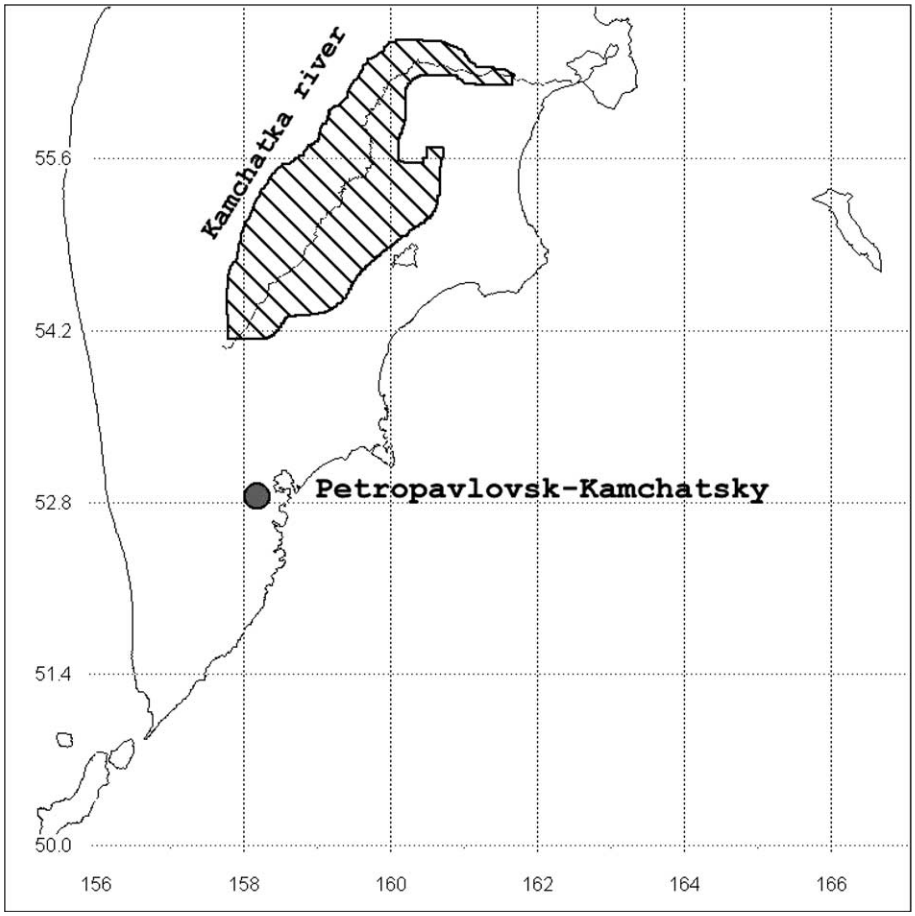

Fig. 1. Central and south part of Kamchatka peninsula. Circle—ground test site, crosshatched region—thermal anomaly area.

Karimshino (52° 56′ N, 158° 15′ E) near Petropavlovsk–Kamchatsky (Fig. 1). We use the data from three deep boreholes (w1, w2 and w4 hereafter) and one hot spring (s1). The following parameters were analysed: water flow rate (Q_w), pH value, water temperature (T_w), ion content (eight components) and gas content (seven components) of the water together with air temperature (T_a) and atmospheric pressure (P_a) in the vicinity of the wells and spring. T_a was calculated as mean value per day. All wells are situated close each other and we chose one of the wells to represent the ground data. A Russian–Japan geophysical observatory complex for electromagnetic and acoustic research is also situated in Karimshino.

Satellite observations are based on NOAA satellite images stored in Satellite Active Archive (NOAA). Four periods of earthquake observations from satellites were selected depending on weather conditions, earthquake location, depth, magnitude and ground data accessibility (Table 1). Preliminarily ten periods were chosen, but after weather condition analysis six events were rejected. We also chose five periods of air temperature observations on the test site (Table 1). Two periods are common

Table 1
Selected earthquakes in Kamchatka region

Date	North	East	Depth, km	Magnitude	Satellite observations of the surface temperature	Air temperature observations
24 Jun 1983	53° 46′	158° 37′	180	6.3	+	
2 Mar 1992	52° 55′	159° 53′	32	7.1		+
8 Jun 1993	51° 13′	157° 50′	70	7.5	+	+
21 Jun 1996	51° 34′	159° 07′	20	7	+	+
5 Dec 1997	54° 50′	162° 2′	4	7.8		+
1 Jun 1998	52° 53′	160° 4′	35	6.0		+
8 Oct 2001	52° 38′	160° 13′	33	6.4	+	

for both data sets—earthquakes of 8 June 1993 and 21 June 1996.

3. Method

Taking into account the distance between hypocentre and test site we use set of specially developed seismic indexes K_s as indicator of seismic activity instead of magnitude values. Index K_s represents a magnitude normalised to epicentral distance and time averaged. It is impact of seismic event to test site by implication. The set of hydrogeochemical parameters (HGP) was also calculated. We construct both HGP-K_s normalised differences for each well and spring and compare them for the different sites.

Satellite image processing includes standard procedures for thermal IR images: data extraction, calibration, radiation and atmospheric corrections. The ground temperature was retrieved according to Becker's algorithm, using bands 4 and 5 (Becker and Li, 1990). The emissivity was set to 0.98 for both bands. As a result, first step temperature images of the earth surface were obtained. On the next step a thermal anomaly was selected, its area and temperature measured. A background area was selected on the plain on the east coast of Kamchatka (~55° 48′ N, 161° 30′ E). During the night such a plain is the warmest place onshore. All pixels in similar meteorological conditions with a temperature exceeded the average value could be considered an anomaly. The average values and standard deviations for the background area were calculated. Then all values on the image below average level plus two standard deviation were removed. Water surfaces and clouds were masked and excluded. Thus the thermal anomaly image was obtained. On this image the anomaly area and temperature were measured and registered to database. Only night scenes were used. The distance from the hypocentre to the thermal anomaly was calculated assuming that the centre of anomaly locates on 55° 36′ N, 159° 42′ E in the basin of Kamchatka river.

4. Results

First the air temperature in a relation to several earthquakes was analysed. The results look promising. Only two examples of air temperature variations are shown here (Figs. 2 and 3). The water flow variations of hot springs are given for reference.

A clear increase of the air temperature was observed for these cases. T_a variations at w1 and w2 show practically the same pattern, demonstrating a large-scale temperature increase by +3–4 °C about 5–20 days before the earthquake. Taking into account other cases we can extend the period—up to 40 days. In both cases we also see a coseismic outburst of water in the hot springs and a insignificant increase of water flow about 20 days before the shock for 8 June 1993. A clear anomaly in the water flow was observed 10–40 days before the shock in case of the 21 June 1996 earthquake.

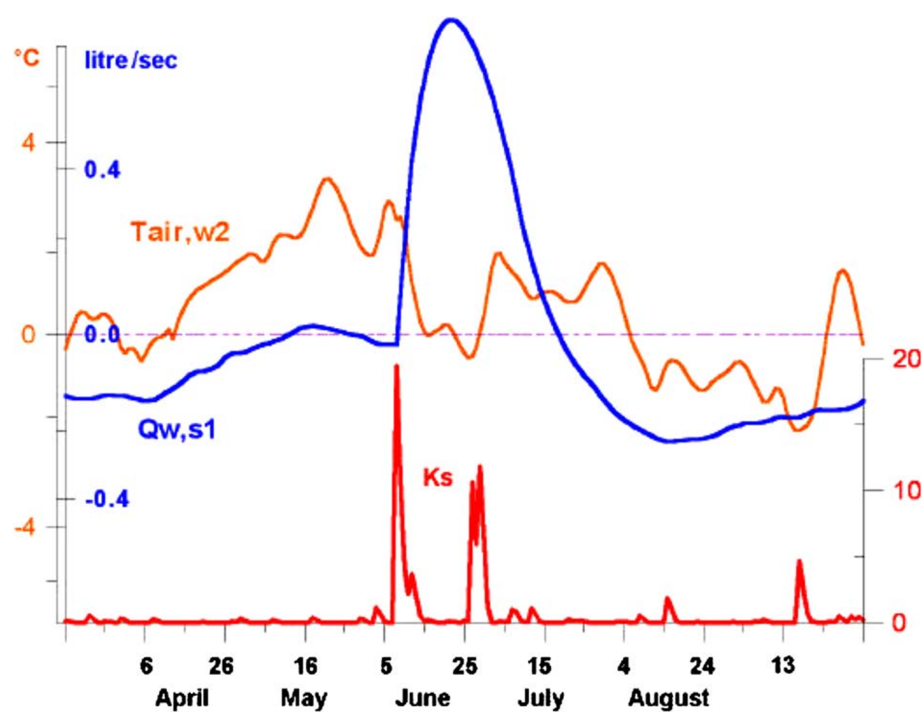

Fig. 2. Variations of the air temperature T_a near well #2 (w2) and the water flow rate Q_w in hot spring (s1) associated with the earthquake 8 June 1993. T_a and Q_w are normalized differences, and measured in °C and l/s respectively. Major time ticks here are 20 days and minor ticks are 10 days.

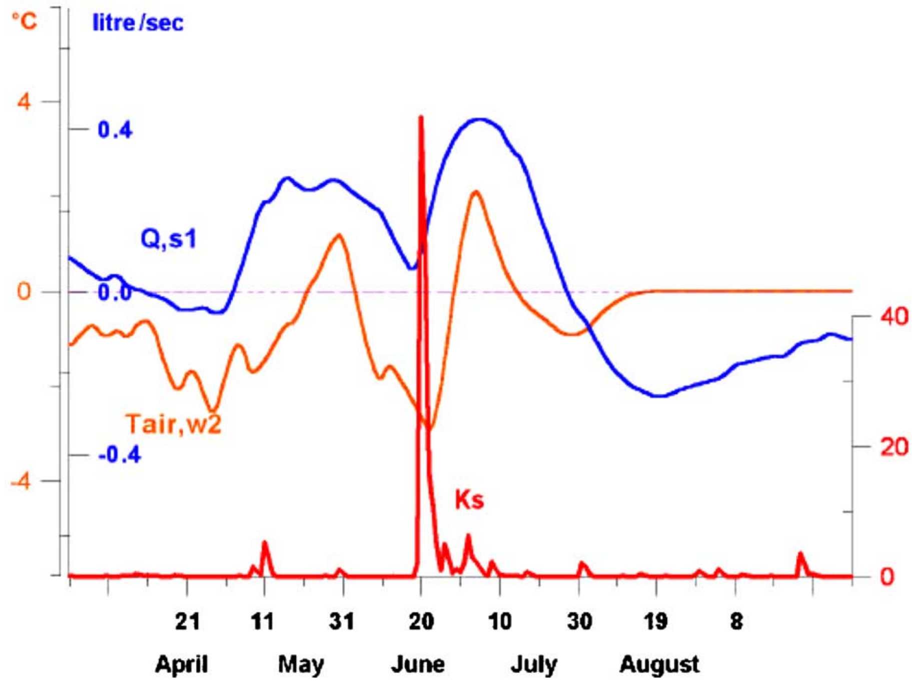

Fig. 3. Variation of the air temperature and water flow rate associated with the earthquake 21 June 1996. All details see Fig. 2.

In the next step we moved from the study of air temperature—earthquake relations to statistical analysis. The result of such type of analysis is presents in Fig. 4.

Correlation analysis of the long series of observations indicates relatively high values of correlation coefficients in 1992–1993 in range of 0–10 days before the shock. After the earthquake we see a weak relation. We can explain such high correlation in this period of sharp air temperature anomalies related with earthquakes in 1992–1993 (Fig. 2). The opposite picture is seen for the period of 1996–1999 (Fig. 3). One can see high values after the shock and small anomalies before. Time of positive correlation lies inside ±10 day around the event in both periods.

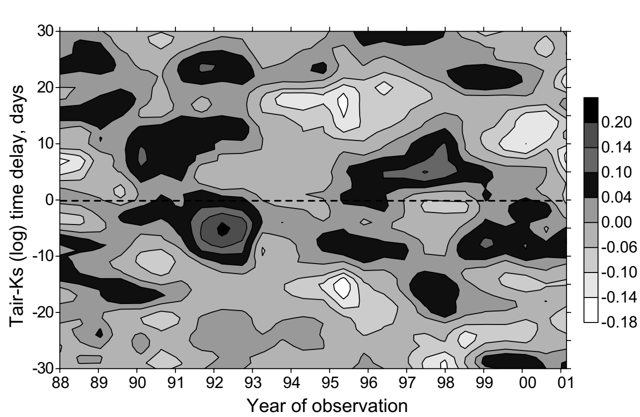

Fig. 4. Correlation diagram of air temperature and seismic activity from 1988 till 2001. Zero level indicates moment of shock. Scale indicates the value of correlation coefficient.

Satellite observations show the presents of an IR thermal anomaly on the Kamchatka peninsula. We confirmed this anomaly for three earthquakes in Kamchatka region. One example of thermal anomalies in Kamchatka is shown on Figs. 5 and 6.

Five days before the shock 17 June 1996 the anomaly was located on the east shore of the peninsula and in the basin of Kamchatka river (Fig. 5). Immediately after the shock 22 June 1996 large scale anomaly was detected in

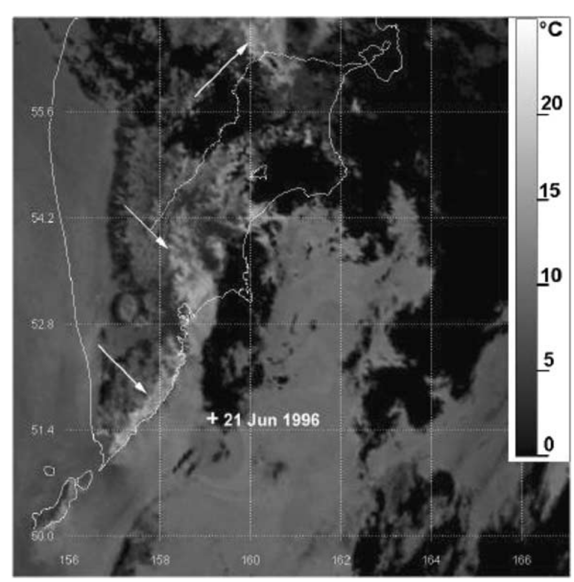

Fig. 5. NOAA thermal image, Kamchatka, thermal anomaly, NOAA—14, 17 June 1996, 16:11:12 GMT. Arrows show thermal anomaly, cross—earthquake epicentre 21 June 1996.

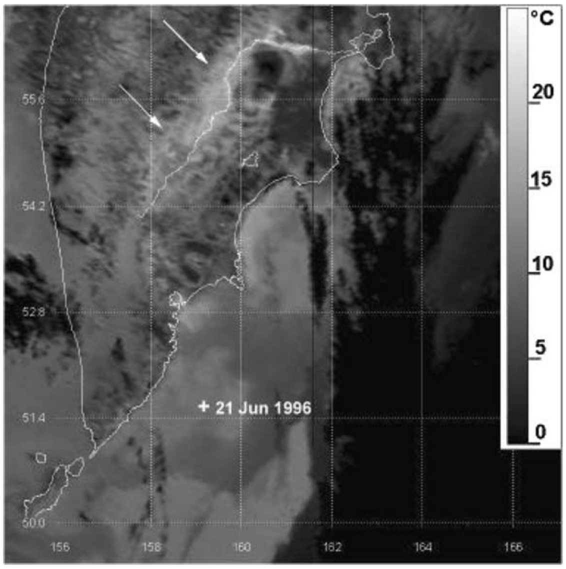

Fig. 6. NOAA thermal image, Kamchatka, thermal anomaly, NOAA—14, 22 June 1996, 16:57:28 GMT. Arrows show thermal anomaly, cross—earthquake epicentre 21 June 1996.

the basin of Kamchatka river (Fig. 6) at the centre of the peninsula. The valley of Kamchatka river is a famous artesian basin with numerous hot springs situated along the 'thermal lines' (Makarenko, 1963). The result of image interpretation and well observations is shown on Fig. 7 .

Water temperature started to rise 8 June 1996, and the most significant increase was recorded from 17 June 1996. Water debit showed insignificant increase from 12 to 18 June 1996. Immediately before and after the shock (21 June 1996) the water debit increased drastically. We can compare the results of air temperature and water flow observations (Fig. 3) and water and thermal anomaly temperature (Fig. 7). Water flow and air temperature have this maximum values about 10–15 days before the shock, while water temperature and thermal anomaly temperature start to increase about 7 days before the event.

Another case of thermal anomalies and well observations is shown in Fig. 8.

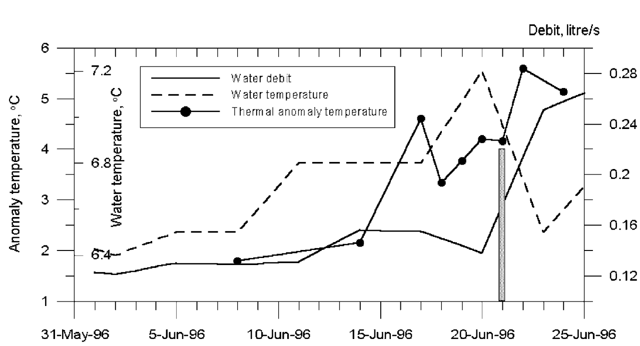

Fig. 7. Well observations (well w4) and thermal anomaly temperature response on earthquake 21 June 1996 in Kamchatka.

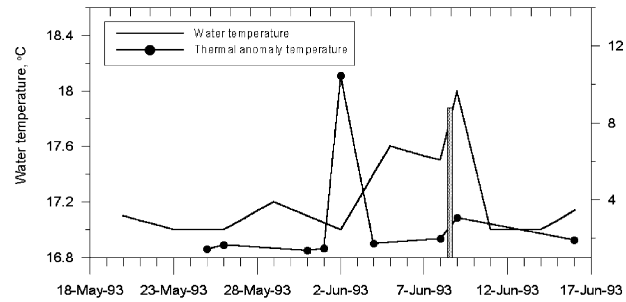

Fig. 8. Well observations (well w1) and thermal anomaly temperature response on earthquake 8 June 1993 in Kamchatka.

The earthquake of 8 June 1993 had the largest magnitude of the shocks considered here. The thermal anomaly recorded at 2 June 1993 covered large part of peninsula, had an unusual shape and intensity—up to 10 °C. Water temperatures also started to increase on this day and continued to grow up to the day of the earthquake—8 June 1993. In this case we can also compare simultaneous satellite and ground observations in this case (Figs. 2 and 8). Both ground and satellite observations indicate an increase of air, water and surface temperature before the shock.

We did not find any thermal anomaly prior to and during the event of 24 June 1983 with a hypocentre depth 180 km, regardless of the fact that this earthquake was located closer to Kamchatka river artesian basin then other shocks. We interpreted it by big depth of epicentre.

5. Discussion

Numerous hydrogeological phenomena, alterations on the earth surface and atmosphere, ionospheric phenomena related to earthquakes encourage us to consider litho–atmo–ionospheric coupling in seismic processes. Now such model is developing. We guess the fluid is essential part of the seismic processes. May be it is not that fluids generate earthquakes (Nur and Booker, 1972). In any case fluid rises to the earth surface. Depending on geological and tectonic situations, near the surface, at a depth of a few kilometres, the fluid is separated into water and gas. The water causes change of debit, temperature and chemical composition in wells and springs. Gas (H_2, He, CH_4, CO_2, O_3, H_2S, Rn) moves to the atmosphere (Wakita et al., 1978). Depth and magnitude of the shock and geological conditions determinate the mosaic character of these phenomena on the earth's surface. This statement is confirmed by the observations of water temperature, debit, pH in wells and thermal anomalies in Kamchatka.

This way heat, water vapour, gas reaches the earth surface. In fact only here the litho–atmospheric coupling starts. We examined a few mechanisms of interaction.

First—convection heat flux (hot water and gas) changes the temperature of the earth surface and air. Second—change of the water levels with usual temperature leads to changes in soil moisture, and consequently the physical properties of the soil. The difference in physical properties means a different temperature on the surface. Third—greenhouse effect, when the optically active gases (CO_2, CH_4, water vapour) escape from the surface. These gases absorb IR radiation, warm up and heat the surface. As a result of gas and water appearing at the surface we expect to find changes in temperature, humidity and atmospheric pressure in surface air.

Next step is the transfer of energy to upper atmosphere and ionosphere. Gravity waves are considered now as the only mechanism to transmit the energy from the surface to upper layers (Molchanov et al., 2001). Gravity waves caused by density or temperature change on the surface. Thermal anomalies, related with seismic activity are considered as one of the possible source of gravity waves. These waves have an important feature: the amplitude of the wave increases with altitude. Gravity waves are able to explain the 'seismic' change in the stratosphere: ozone concentration (Tronin, 2002), high clouds, and ionosphere.

We would like also to make some recommendations about air temperature measurements. It was determined that night temperature observations show a maximum correlation with seismic activity (Tronin, 1996). We expect that the correlation between seismic activity and air temperature will be improved if night (not diurnal) data will be included in the analysis. It will be profitable also to establish a ground observatory in the Kamchatka river basin that drains the large artesian basin. Such system should be very sensitive to the earthquake preparation processes.

6. Conclusion

Results of investigations in air temperature and thermal anomalies in Kamchatka indicate: (1) air temperature increases were observed ±10 days around strong shocks; (2) the amplitude of the anomaly is about 3–4 °C; (3) thermal anomalies appeared about 4–7 days before and continued about a few days after earthquake (post-seismic effect of earthquakes in China and Middle Asia continues 1 or 2 weeks); (4) the anomaly was sensitive to crust earthquakes with a magnitude more than 6 and for distance up to 500 km, no reaction on deep earthquakes; (5) the size of anomaly is about 300 km in length and 75 km in width; (6) the amplitude of the anomaly varies from 2 to 10 °C; (7) thermal anomaly has a mosaic internal structure with average element size about 40×130 km; (8) the response of water in wells and surface temperature in thermal anomaly on earthquake look similar; (9) increase of air and surface temperature as a consequence of the hot water eruption about 10 days before strong earthquakes could lead to atmospheric perturbations (atmospheric gravity waves) and could be helpful to explain an origin of some preseismic electromagnetic effects (in the ULF, VLF, LF frequency range); (10) we can recommend to set ground test site for earthquake monitoring in the basin of Kamchatka river.

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