THE CARTOGRAPHIC JOURNAL
https://doi.org/10.1080/00087041.2017.1414020

REFEREED PAPER

History of the Cartography and Toponymy of the Valley of Geysers (Kronotsky Reserve, Kamchatka Peninsula, Russia): From Field Drawings to 3-D Documents

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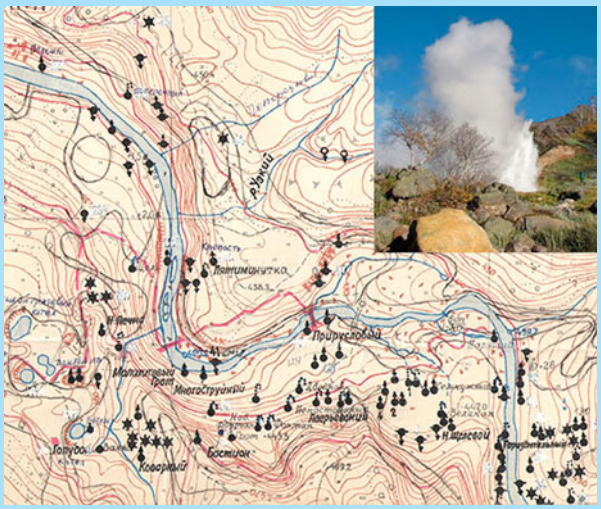
ABSTRACT

The article describes the evolution of the cartography and toponymy of the second largest geyser field in the world – the Valley of Geysers in the Kronotsky Reserve (Kamchatka Peninsula, Russia), discovered in 1941. The toponymy evolved in close connection with the development of the cartographic base that passed through the three stages from the first manual drawings to large-scale maps and to 3-D models of the territory. The number of geysers with personal names increased gradually from twelve to more than one hundred. The article presents examples of diagrams and maps as well as tables of thermal features with coordinates. All main sources of literature were analysed for the period of 1941–2017, and the article presents a comprehensive historiography on the investigated topic. The evolution of instruments for the measurement of geyser activity is also briefly overviewed with examples of data obtained using the different methods.



KEYWORDS

Kamchatka; ~~Geyser~~; cartography; toponymy; measurement of geyser activity; history

Introduction

The Valley of Geysers is the second largest geyser field in the world after Yellowstone National Park, United States (Bryan, 2008: 422). The field is located in the remote and hard to access central part of the Kamchatka Peninsula near its eastern coast. Although two minor geysers in the south of Kamchatka Peninsula were described as early as the eighteenth century (Krasheninnikov, 1755), the Valley of Geysers was completely unknown to people before 1941.

The geysers of the Valley of Geysers were described systematically in several publications (Bryan *et al.*, 1991; Leonov, 2012a; 2012b; 2017; Naboko, 1954; Nechayev, 2000; 2007; Raik, 1963; Semenov, 1973; Sugrobov *et al.*, 2004; 2009; Sugrobova, 1982; Ustinova, 1946b; 1949; 1955; Vinogradov, 1964). Although later descriptions generally considered the previous ones, the evolution of toponymy was in no way a linear process. Old names went out of use and new names arose; some thermal features disappeared and others emerged, especially after two catastrophic landslides in 2007 and 2014 (Leonov and Leonov, 2014).

The history of cartography and toponymy of the Valley of Geysers can be divided into three main stages. In the first stage, the location and names of geysers and other geothermal features were documented using manual maps

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(1941–1975). In 1975, the large-scale topographic map of the region was published, which became the basis for the second stage of mapping and naming of geysers that lasted for more than 30 years. A catastrophic landslide in 2007 led to the emergence of new geysers and hot springs and accordingly a new stage of evolution of the toponymy. This event also inspired a new wave of investigations of the Valley. The third stage began in 2009 when the first high-resolution multispectral satellite image of the territory was produced and accurately georeferenced in the WGS84 coordinate system, and the data of remote sensing started to be used actively to prepare geo-referenced maps and 3-D models of the territory.

Generally, these three periods coincide with the stages of the development of tools for the measurement of geyser activity including manual measurements (1941–1971), automatic measurements using water level gauges (1972–late 1990s), sensors based on contact closure (1988–2006), autonomous temperature loggers (since 2007) and long-term automatic videotaping (since 2014).

History of the discovery

The discovery of large geysers in Kamchatka in 1941 was one of the significant geographical events of the twentieth century. Seven of the discovered geysers had a fountain size larger than ten metres.[1] The total number of geysers was estimated as more than one hundred: 'В долине речки Гейзерной находится не менее 22 крупных и около сотни мелких гейзеров' (There are no less than 22 large and approximately one hundred small geysers in the Valley of the Geyzernaya River) (Vlodavets, 1949: 96). This estimation was confirmed later by several researchers including the expedition of the American Geyser Observation and Study Association (GOSA) in 1991: '… we actually watched no fewer than 116 geysers actually in eruption … Certainly there are many geysers that we never saw … ' (Bryan *et al.*, 1991: 10).

Geysers are primarily grouped in the lower basin of a small river, which originates on the west slopes of the Kikhpinych volcano. The river was unnamed before 1941 and then named the Geyzernaya (*geyser*) River. This river is a tributary of the Shumnaya (*noisy*) River that flows from neighbouring Uzon Caldera to the south-east and ends in the Pacific Ocean. There are also two known geysers in the Uzon Caldera (one is extinct and one is active), Figure 1.

The territory in the central part of the eastern coast of the Kamchatka Peninsula belongs to the Kronotsky State Natural Biosphere Reserve established in 1934. The discovery of geysers was a result of an expedition organized by the authorities of the reserve to investigate the upper reaches of the Shumnaya River and clarify the location of its origin. Although the origin was shown on existing small-scale maps, employees of the reserve and local hunters doubted the correctness of the maps in this area.

Two employees of the Kronotsky Reserve – geologist Tatiana Ustinova (1913–2009) and observer Anisifor Krupenin (1914–1990) – followed the Shumnaya River upstream, travelling by dog sled. On April 14, 1941 they reached an unnamed tributary and stopped for a dinner. A large geyser suddenly erupted on the opposite river bank. This geyser was later named Pervenets (*firstborn*). The first report about the discovery of a geyser on Kamchatka was published by Ustinova and Krupenin on 15 June 1941 in a local newspaper «Kamchatskaya Pravda» (Zhilin, 2014: 34).

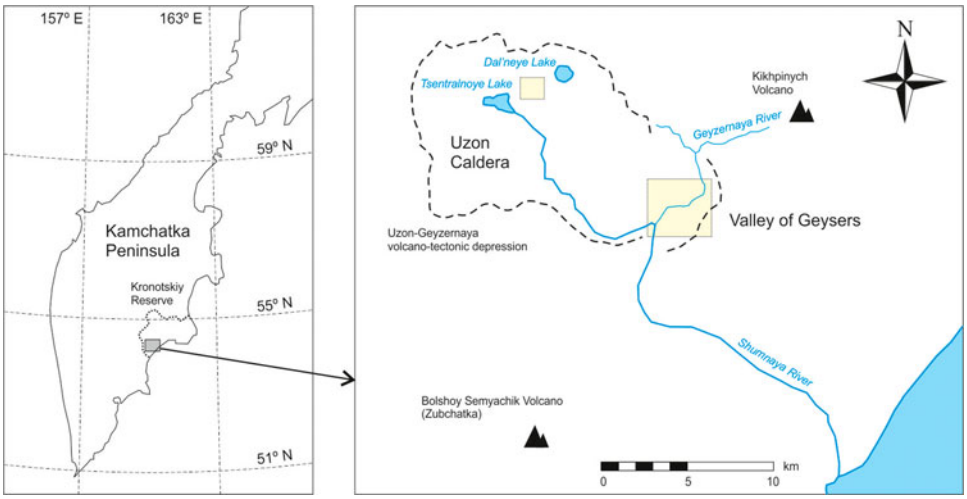


Figure 1. Location of the Valley of Geysers and the Uzon Caldera on the Kamchatka Peninsula. Yellow rectangles show the areas where geysers and boiling springs are located.

In July 1941, the second expedition was organized with the same participants. The basin of the unnamed river was explored and the main group of geysers was discovered. The war with Nazi Germany (1941–1945) hindered further investigations, and in 1945 the third expedition was organized. Ustinova and Krupenin were joined by Yuri Averin (the husband of the Ustinova and the director of the Kronotsky Reserve). The first photographs of the Valley of Geysers were taken in 1945 during this expedition, mainly by Averin.

Ustinova wrote the first description, mapped the main geysers, and provided them with names. In 1946, she published two scientific articles (Ustinova, 1946a; 1946b). The first article describes only the first discovered geyser (without a name), whereas the second one contains descriptions of the twelve geysers with names and several of the unnamed geysers. One more article was published by Ustinova in 1949 with the description of the same twelve geysers, the first map of the location of the geysers and the results of a chemical analysis of the water (Ustinova, 1949). In 1951, Ustinova took part in one more expedition to the Valley and in 1955 finally published 20,000 copies of her famous book (Ustinova, 1955). The book contained a detailed description of the discovered thermal field, including 25 main geysers and two main boiling springs.

Furthermore, Ustinova never called the discovered place, 'the Valley of Geysers,' at least in her publications. The name 'Valley of Geysers' first appeared in print in 1952 in the Large Soviet Encyclopaedia (Ovchinnikov, 1952), but its author is unknown.

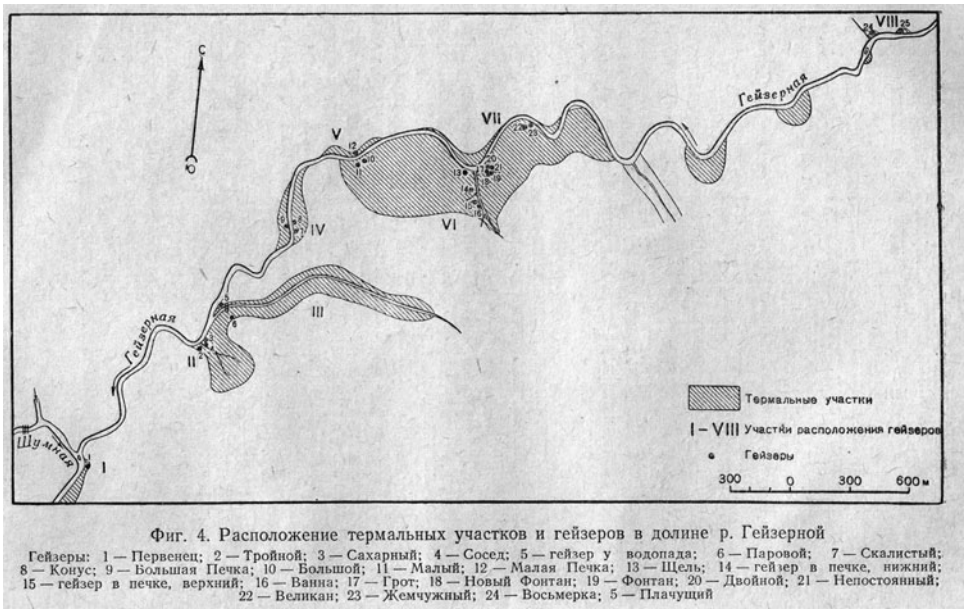
1941–1975: A time of manual schemes

Before the expeditions of Ustinova and Krupenin in 1941, only a small-scale map of the investigated territory existed, which was based on interview data (Ustinova, 1955: 5). The upper course and origin of the Shumnaya River were mapped incorrectly on this map. The small-scale map was corrected in 1943 based on the results of the 1941 expeditions (Zhilin, 2014: 51) but no large-scale topographic map of the investigated area was published until 1975.

During 1941–1975, the mapping of the geysers and other objects was based on manual drawings based primarily on field surveys of the territory. Some researchers probably used small-scale military maps (1:100 000 and smaller) and black-and-white military aerial photographs but their scale was not adequate for mapping individual thermal features and could only be used for general orientation. For example, the area with greatest concentration of geysers occupies only approximately 2 square cm at a scale of 1:100 000.

In the absence of published large-scale maps, researchers needed to prepare their own manual large-scale maps of the territory. These manual maps contained only simple hydrography and approximate contour lines, Figures 2–6.

The first set of maps was prepared and published by Ustinova, including a general map of the locations of the geysers in the lower basin of the Geyzernaya River, Figure 2, and large-scale maps of the most interesting thermal areas (an example is shown on Figure 3). She named 22 geysers and two large boiling springs. Twenty-five geysers are shown on her map including the 22 geysers with individual names and 3 geysers with descriptive titles, Figure 2 (Ustinova, 1955).



Фиг. 4. Расположение термальных участков и гейзеров в долине р. Гейзерной

Гейзеры: 1 — Первенец; 2 — Тройной; 3 — Сахарный; 4 — Сосед; 5 — гейзер у водопада; 6 — Паровой; 7 — Скалистый; 8 — Конус; 9 — Большая Печка; 10 — Большой; 11 — Малый; 12 — Малая Печка; 13 — Щель; 14 — гейзер в печке, нижний; 15 — гейзер в печке, верхний; 16 — Ванна; 17 — Грот; 18 — Новый Фонтан; 19 — Фонтан; 20 — Двойной; 21 — Непостоянный; 22 — Великан; 23 — Жемчужный; 24 — Восьмерка; 5 — Плачущий

Figure 2. General map of the location of geysers in the book of Ustinova (1955).

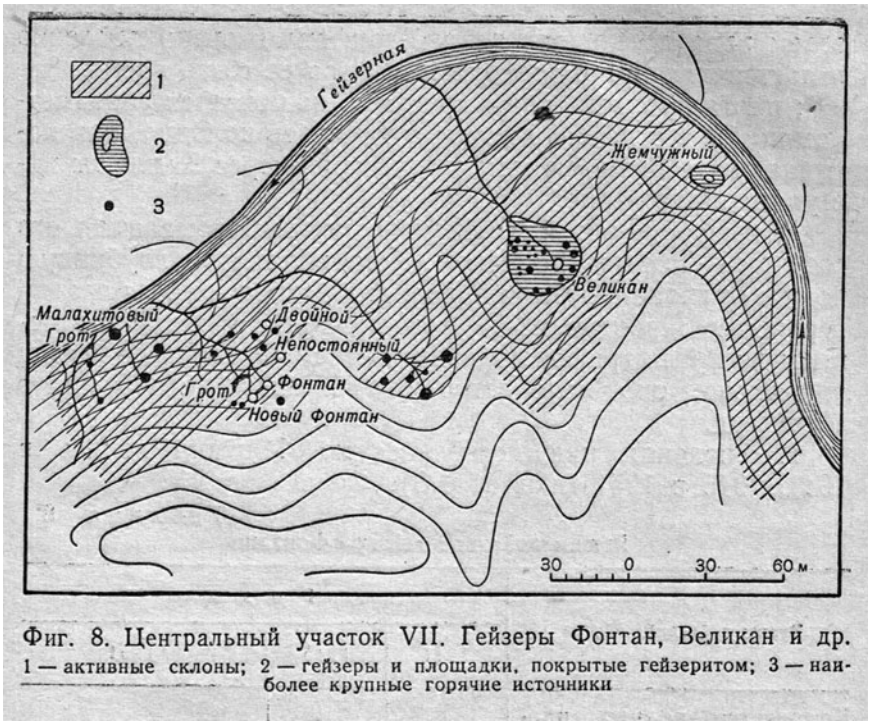


Figure 3. Map of the VII thermal area in the book of Ustinova (1955).

Sofya Naboko described two more geysers with individual names. No map is given in her article (Naboko, 1954).

Ants Raik described five new geysers with individual names. At the same time, several geysers from Ustinova's book were not included in Raik's systematic description. Twenty-three geysers are described in detail in Raik's publication and 22 of them are shown on a map (Raik, 1963).

Vladimir Vinogradov described two new geysers and four boiling springs with individual names. Thirty thermal features are shown on his map: nineteen geysers and eleven springs, Figure 4 (Vinogradov, 1964).

In 1964, an official tourist route («All-Union tourist route № 264») to the Valley of Geysers was established. Large groups of tourists from all regions of the Soviet Union also started informally contributing to the naming of minor thermal features.

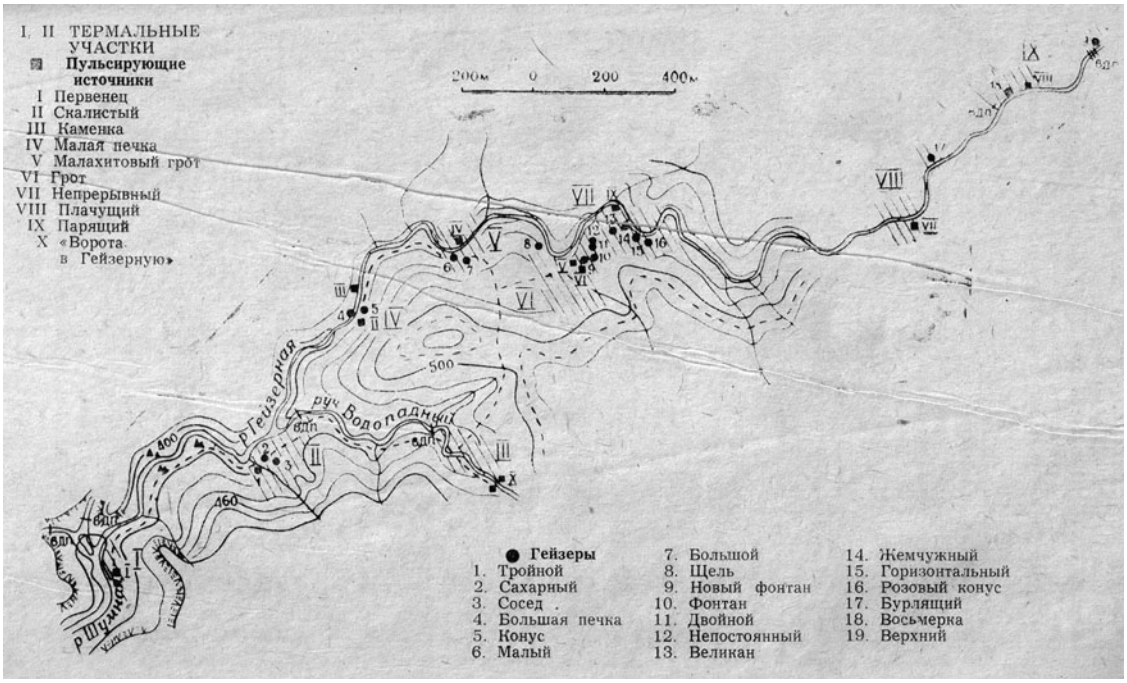


Figure 4. Map of the location of geysers in the article of Vinogradov (1964).

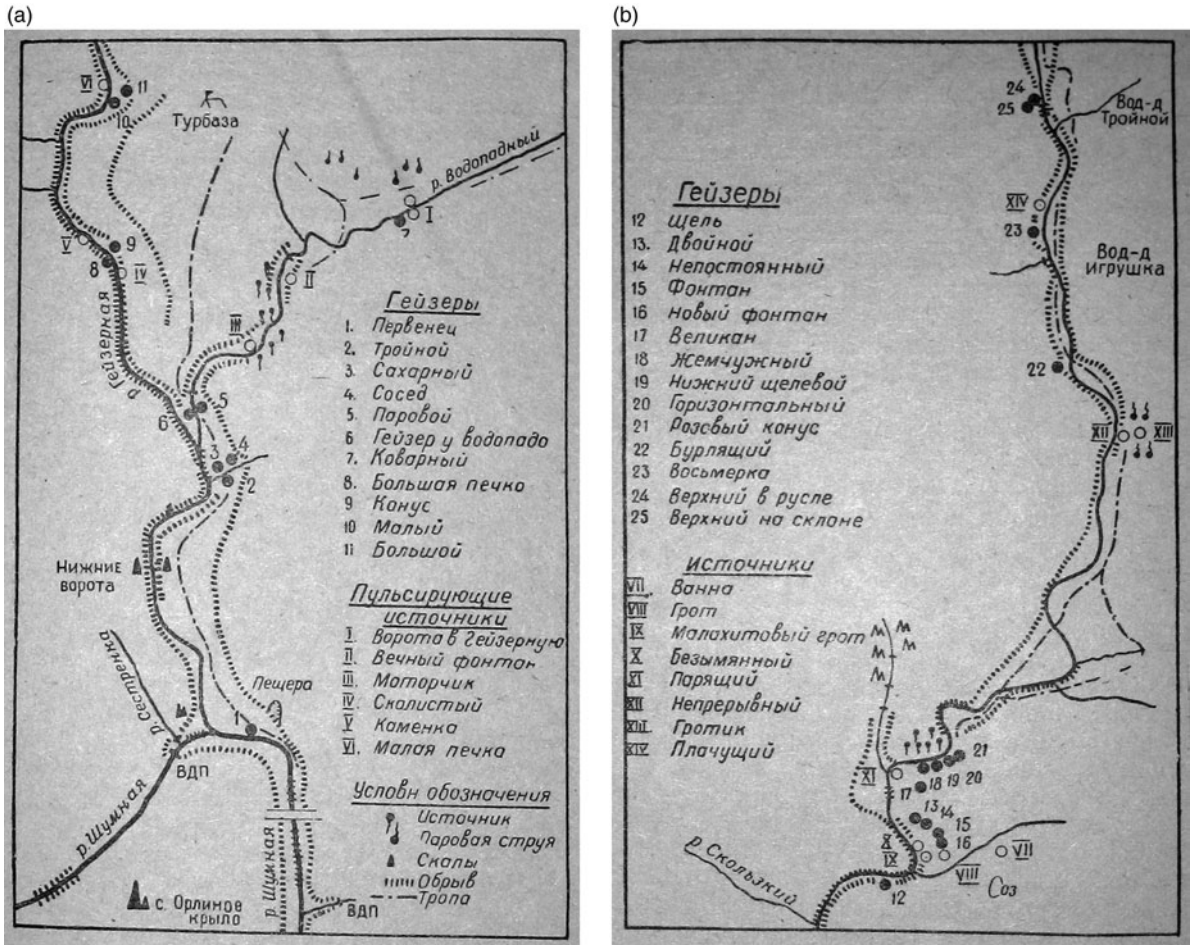


Figure 5 (a, b). Maps of the location of geysers in the book of Semenov (1973).

Vladimir Semenov, a famous popularizer of the tourism in Kamchatka (and in the Valley of Geysers in particular), devoted a quarter of his book to the description of the Valley of Geysers and its thermal features (Semenov, 1973). Forty geysers and springs with individual names are shown on two maps in his book, Figure 5. Some of these were possibly named by Semenov or unknown tourists. He also likely prepared a simple map of the Valley of Geysers for two popular tourist booklets (Semenov, 1974; 1975); this map contains 28 geysers and springs with individual names, Figure 6.

In 1976, the Valley was officially closed to visitors because of the resource damage caused by tourists. Nevertheless, many tourists continued to visit the Valley unofficially.

Thus, the first stage of mapping and naming of the thermal features continued for approximately 30 years and was based on manual maps of the territory. The initial toponymy established by Ustinova was later expanded by other researchers and tourists. The number of thermal features with individual names in systematic descriptions grew successively from 12 (1946) to 25 (1955), 30 (1964) and 40 (1973). Considering all the names (including the descriptive ones) from all publications during 1941–1975, the total number of named geysers and boiling springs reached 48 by 1975, see Table 1.

1975–2009: A time of large-scale maps

In the early 1970s, the research activity in the Valley changed.

In 1971, systematic geological and geothermic investigations in the basin of the Geyzernaya River and neighbour areas were started by scientists[2] of the Institute of Volcanology of the Far Eastern Branch of the Academy of Sciences of the USSR (hereinafter 'Institute of Volcanology') led by Viktor Sugrobov. These methodical studies stopped in 1994 after the disintegration of the USSR and a crucial decrease in financing. The construction of a wooden house was started by scientists in 1972 to make life in the Valley more comfortable and enable year-round geyser observation. Before 1972, temporary tents housed reserve employees, researchers and tourists during summer time.

At the same time, in view of the increasing tourist load, the authorities of the reserve decided to actively manage the area. Since 1970, Vitaly Nikolayenko became a permanent employee of the reserve at the headquarters of the

Figure 6. Map of the location of geysers in tourist booklets (Semenov, 1975).

Valley of Geysers. Soon afterwards, he built his own two-story house attached to the one-story house of scientists; these two initial buildings gave birth to the famous 'old house in the Valley of Geysers.' For more than two decades, this residence was a base for protection of the area and scientific research as well as a shelter for numerous unofficial tourists who managed to reach the Valley. The GOSA expedition, welcomed by Nikolayenko, also lived in this house in 1991. This house was destroyed by fire in 1996.

Soon after the beginning of the regular geological and geothermal research studies, Sugrobov initiated the creation of a large-scale map of the main thermal field (1:2 000) and a large-scale map of the basin of the Geyzernaya River (1:10 000). Large-scale topographic mapping and aerial photography was performed in 1973; the originals of the maps were prepared in 1974 and published in 1975 with 300 copies of each type (Dvigalo and Melekestsev, 2009). The location of 25 geysers and boiling springs were shown on the 1:2 000-scale map. The creation of large-scale maps was the result of the collaboration of specialists from the Institute of Volcanology and Novosibirsk Institute of Engineers in Geodesy, Aerophotography and Cartography (NIIGAiK).

The maps were produced in the conventional coordinate system but did not contain geographical coordinates. Nevertheless, the maps were classified as 'secret' (1:10 000) and 'for restricted use' (1:2 000) and their use for scientific research was possible only by special permission. Soon after the publication, Sugrobov unofficially gave one exemplar of the map (1:2 000) to Nikolayenko. Later, he also organized the official transfer of one or two exemplars of maps from the Institute of Volcanology to the Kronotsky Reserve. However, the secret status made it impossible to publish these maps (and derivative maps and diagrams) for public access.

Soon after the publication, field researchers started using both maps for mapping thermal and other physical features. They manually wrote the symbols and names of numerous small geysers, springs and creeks on the maps, Figures 7 and 8.

Thus, 1975 can be considered the starting point for the second stage of the mapping of thermal features in the Valley.

During the 1970s and 1980s, the research and tourist activity in the Valley of Geysers was at its apogee. Although the initial toponymy of Ustinova remained practically untouched, many other thermal features received alternative names, Table 1. Additionally, several dozen minor geysers and boiling springs were named by scientists and tourists, Table 2. These individuals also named many other thermal features (mudpots, pools, steam vents, thermal walls and platforms) and other geographical objects (lakes, rocks, creeks, waterfalls). The process was never regulated by the authorities of the reserve, resulting in duplication and triplication of names for many thermal features as well as using similar names for different features. This spontaneous naming activity together with the absence of large-scale maps in public access caused a gradually increasing naming confusion.

Generally, during the second stage, two traditions manifested themselves in the naming of geysers, boiling springs and other objects. These traditions can be referred to as 'scientific' and 'touristic'.

The names used by researchers were documented primarily in their field books and work papers, and partially in several scientific articles. For example, in 1982, an article was published with the results of the automatic measurement of geyser activity during 1972–1978. These results were compared with data collected manually during 1941–1971, and an analysis of the influence of different factors on geyser activity was performed (Sugrobova, 1982). In 1989, an article was published with the analysis of the tritium concentration in thermal

Table 1. Geysers and boiling springs with names that were first mentioned in publications during 1941–1974 years.

#	ID[1]	Published names[2]	Longitude (E)[3]	Latitude (N)[3]	Status
1	1PER	**Первенец (Pervenets, *firstborn*)** (Ustinova, 1946b)	160°7′25,032″	54°25′41,264″	Active
2	2SAK	**Сахарный (Sakharnyy, *sugary*)** (Ustinova, 1946b)	160°7′44,079″	54°25′54,024″	Buried in 2007
3	2SOS	**Сосед (Sosed, *neighbour*)** (Ustinova, 1955)	160°7′44,301″	54°25′54,028″	Buried in 2007
4	2TRO	**Тройной (Troynoy, *triple*)** (Ustinova, 1946b)	160°7′44,199″	54°25′53,485″	Buried in 2007
5	3FAK	Вечный фонтан (Vechnyy fontan, *eternal fountain*) (Semenov, 1973) **Факел (Fakel, *torch*)** (Sugrobova *et al.*, 1989)	160°8′8,866″	54°25′59,781″	Buried in 2007
6	3PAR	**Паровой (Parovoy, *steamer*)** (Ustinova, 1955)	160°7′50,455″	54°25′58,303″	Buried in 2007
7	3SHU	Коварный (Kovarnyy, *treacherous*) (Semenov, 1973) **Шутник (Shutnik, *joker*)** (Bryan *et al.*, 1991) Банный (Bannyy, *bathing*) (Nechayev, 2000; Nechayev, 2007) Теремок (Teremok, *small fairy-tale house*) (Sugrobov *et al.*, 2009)	160°8′16,623″	54°25′57,687″	Buried in 2007
8	3UVO	гейзер у водопада (geyzer u vodopada, *geyser near the waterfall)* (Ustinova, 1955) **Скрытный (Skrytnyy, *hidden*)** (Bryan *et al.*, 1991) **У Водопада (U Vodopada, *near the waterfall*)** (Sugrobov *et al.*, 2009)	160°7′48,885″	54°25′58,857″	Buried in 2007
9	3VGG	**Ворота в Гейзерную (Vorota v Geyzernuyu, *gate to the Geyser valley)*** (Vinogradov, 1964)	160°8′17,075″	54°25′57,421″	Buried in 2007
10	3VGI	*(a pair of thermal features: geyser and boiling spring)*	160°8′17,276″	54°25′57,567″	Buried in 2007
11	4BOL	**Большая Печка (Bolshaya Pechka, *large oven*)** (Ustinova, 1946b)	160°7′56,083″	54°26′8,816″	Destroyed in 1981
12	4KAM	**Каменка (Kamenka, *stone oven*)** (Ustinova, 1955)	160°7′56,143″	54°26′11,16″	Buried in 2007
13	4KON	**Конус (Konus, *cone*)** (Ustinova, 1955) Конус Хрустальный (Konus Khrustalnyy, *crystal cone*) (Bryan *et al.*, 1991)	160°7′56,986″	54°26′9,221″	Buried in 2007
14	4SKA	**Скалистый (Skalistyy, *rocky*)** (Ustinova, 1955)	160°7′56,671″	54°26′7,91″	Buried in 2007
15	5BOL	**Большой (Bolshoy, *large*)** (Ustinova, 1946b)	160°8′11,884″	54°26′15,661″	Active
16	5MAL	**Малый (Malyy, *small*)** (Ustinova, 1946b)	160°8′9,337″ (before 2007) 160°8′9,508″	54°26′15,672″ (before 2007) 54°26′15,527″	Active, see note #4 below
17	5MPE	**Малая Печка (Malaya Pechka, *small oven*)** (Ustinova, 1946b)	160°8′10,017″ (before 2007) 160°8′9,939″	54°26′16,911″ (before 2007) 54°26′16,823″	Active, see note #4 below
18	6GOL	гейзер в печке, верхний (geyzer v pechke, verkhniy, *geyser in the oven, upper*) (Ustinova, 1955) Печь в воронке, верхняя (Pech v voronke, verkhnyaya, *oven in the hole, upper*) (Ustinova, 1955) гейзер-яма №1 (geyzer-yama №1, *geyser-hole №1*) (Naboko, 1954) **Голубой Котёл (Goluboy Kotël, *sky-blue pool*)** (Semenov, 1974; Semenov, 1975) Верхняя печь (Verkhnyaya Pech, *upper oven*) (Naumenko *et al.*, 1986)	160°8′26,416″	54°26′15,043″	Active
19	6KOV	гейзер-чаша (geyzer-chasha, *geyser-cup*) (Naboko, 1954) **Коварный (Kovarnyy, *treacherous*)** (Sugrobova *et al.*, 1989)	160°8′29,054″	54°26′15,628″	Active
20	6SHC	**Щель (Shchel, *crack*)** (Ustinova, 1946b) Многоструйный (Mnogostruynyy, *multijet*) (Naboko, 1954)	160°8′23,484″	54°26′17,873″	Active
21	6VAN	**Ванна (Vanna, *bath*)** (Ustinova, 1946b) гейзер-ванна (geyzer-vanna, *geyser-bath*) (Naboko, 1954)	160°8′27,643″	54°26′15,055″	Active
22	6VRA	гейзер в печке, нижний (geyzer v pechke, nizhniy, *geyser in the oven, lower*) (Ustinova, 1955) Печь в воронке, нижняя (Pech v voronke, nizhnyaya, *oven in the hole, lower*) (Ustinova, 1955) гейзер-яма №2 (geyzer-yama №2, *geyser-hole №2*) (Naboko, 1954) Дантов Ад (Dantov Ad, *Dante's hell*) (Semenov, 1974; Semenov, 1975) Нижняя Печь (Nizhnyaya Pech, *lower oven*) (Naumenko *et al.*, 1986) **Врата Ада (Vrata Ada, *gates of hell*)** (Bryan *et al.*, 1991)	160°8′25,245″	54°26′15,641″	Active
23	7DVO	**Двойной (Dvoynoy, *double*)** (Ustinova, 1955) Седло (Sedlo, *saddle*) and Стремя (Stremya, *stirrup*) (Bryan *et al.*, 1991)	160°8′30,663″	54°26′18,792″	Active
24	7FON	**Фонтан (Fontan, *fountain*)** (Ustinova, 1946b)	160°8′30,985″	54°26′17,989″	Active

(*Continued*)

Table 1. Continued.

#	ID[1]	Published names[2]	Longitude (E)[3]	Latitude (N)[3]	Status
25	7GOR	**Горизонтальный (Gorizontalnyy, *horizontal*)** (Naboko, 1954)	160°8′37,004″	54°26′21,054″	Active
26	7GRO	**Грот (Grot, *grotto*)** (Ustinova, 1955)	160°8′29,906″	54°26′17,187″	Active
		Грот Юбилейный (Grot Yubileynyy, *jubilee grotto*) (Bryan *et al.*, 1991)			
27	7LES	Безымянный (Bezymyannyy, *unnamed*) (Semenov, 1973)	160°8′27,916″	54°26′17,676″	Buried in 2014
		Многоструйный (Mnogostruynyy, *multijet*) (Sugrobova and Sugrobov, 1985)			
		Леший (Leshiy, *forest spirit*) (Bryan *et al.*, 1991)			
28	7MAL	**Малахитовый Грот (Malakhitovyy Grot, *malachite grotto*)** (Ustinova, 1955)	160°8′27,43″	54°26′17,405″	Buried in 2014
		Грот-источник (Grot-istochnik, *grotto-the-spring*) (Naboko, 1954)			
29	7NEP	**Непостоянный (Nepostoyannyy, *inconstant*)** (Ustinova, 1955)	160°8′30,914″	54°26′18,499″	Active
30	7NOR	Левый карлик (Levyy karlik, *left dwarf*) (Raik, 1963)	160°8′41,13″	54°26′21,027″	Active
		Нора (Nora, *hole*) (Sugrobov *et al.*, 2009)			
31	7NOV	**Новый Фонтан (Novyy Fontan, *new fountain*)** (Ustinova, 1955)	160°8′30,893″	54°26′17,919″	Active
32	7PAR	**Парящий (Paryashchiy, *steaming*)** (Vinogradov, 1964)	160°8′33,72″	54°26′22,485″	Active
		Радужный Король (Raduzhnyy Korol, *rainbow king*) (Nechayev, 2015)			
33	7PLA	Нижний Щелевой (Nizhniy Shchelevoy, *lower slit-type*) (Naboko, 1954)	160°8′36,871″	54°26′21,193″	Buried in 2014
		Плащаница (Plashchanitsa, *Christ's shroud*) (Bryan *et al.*, 1991)			
		Плоский Конус (Ploskiy Konus, *flat cone*) (Sugrobov *et al.*, 2009)			
34	7ROZ	Верхний карлик (Verkhniy karlik, *upper dwarf*) (Raik, 1963)	160°8′40,952″	54°26′20,647″	Active
		Розовый конус (Rozovyy konus, *pink cone*) (Vinogradov, 1964)			
		Конус Розовый (Konus Rozovyy, *pink cone*) (Bryan *et al.*, 1991)			
35	7ROZ.1	Центральный карлик (Tsentralnyy karlik, *central dwarf*) (Raik, 1963)	160°8′40,741″	54°26′20,895″	Active
36	7ROZ.2	Нижний карлик (Nizhniy karlik, *lower dwarf*) (Raik, 1963)	160°8′40,665″	54°26′20,99″	Active, see note #5 below
		Пийп (Piip, *named after B.I. Piip*) (Belousov and Belousova, 2017)	(before 2014) 160°8′40,797″	(before 2014) 54°26′20,948″	
37	7ROZ.3	Правый карлик (Pravyy karlik, *right dwarf*) (Raik, 1963)	160°8′40,496″	54°26′20,734″	Active
38	7VEL	**Великан (Velikan, *the giant*)** (Ustinova, 1946b)	160°8′34,422″	54°26′20,898″	Active
39	7ZHE	**Жемчужный (Zhemchuzhnyy, *pearl*)** (Ustinova, 1946b)	160°8′35,328″	54°26′21,841″	Active
40	8BUR	**Бурлящий (Burlyashchiy, *seething*)** (Vinogradov, 1964)	160°9′29,09″	54°26′32,05″	Active
41	8NEP	**Непрерывный (Nepreryvnyy, *continuous*)** (Vinogradov, 1964)	160°9′21,277″	54°26′25,396″	Buried in 2014
42	8PLA	**Плачущий (Plachushchiy, *weeping*)** (Ustinova, 1955)	160°9′49,76″	54°26′39,32″	Active
43	8RAD	Гротик (Grotik, *grottino*) (Semenov, 1973)	160°9′21,014″	54°26′25,17″	Active
		Радужный (Raduzhnyy, *rainbow*) (Bryan *et al.*, 1991)			
		Большой (Bolshoy, *large*) (Sugrobov *et al.*, 2009)			
		Трубы (Truby, *tubes*) (Kiryukhin, Rychkova, 2011)			
44	8VER	**Верхний (Verkhniy, *upper*)** (Vinogradov, 1964)	160°10′1,94″	54°26′46,43″	Active
		Верхний на склоне (Verkhniy na sklone, *upper-on-the-slope*) (Semenov, 1973)			
45	8VRU	**Верхний в русле (Verkhniy v rusle, *upper-in-the-streambed*)** (Semenov, 1973)	160°10′2,32″	54°26′46,73″	Unknown
46	8VOS	**Восьмёрка (Vosmërka, *8-shaped*)** (Ustinova, 1955)	160°9′42,691″	54°26′38,755″	Active
47	—	Трёхструйный (Trëkhstruynyy, *three-jet*) (Naboko, 1954)	Unknown	Unknown	Unknown
48	—	Моторчик (Motorchik, *little engine*) (Semenov, 1973)	Unknown	Unknown	Buried in 2007

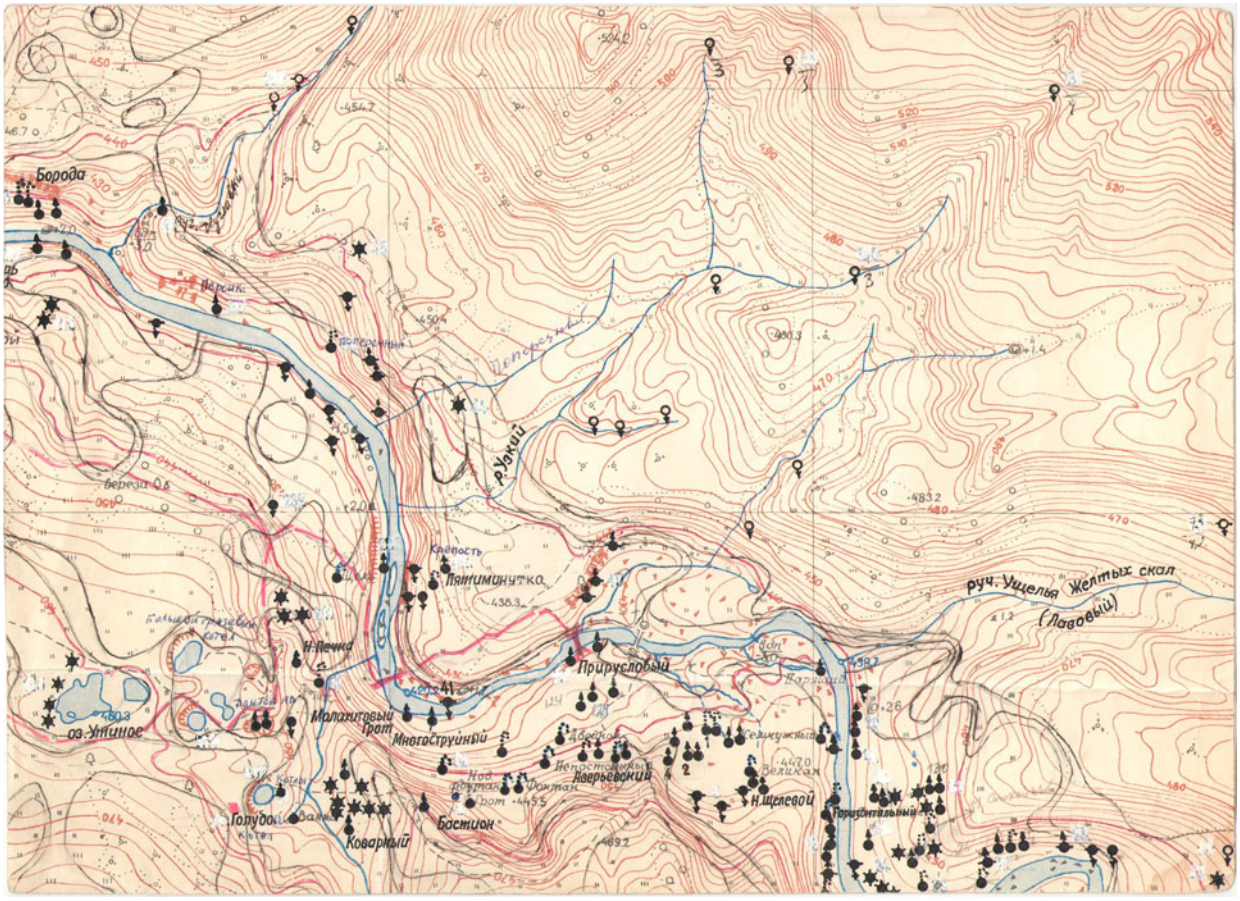


Figure 7. A part of the topographic map (1:2 000) with manually written names and marks of geysers and springs, 1975 (courtesy of Viktor Sugrobov).

water (Sugrobova *et al.*, 1989). These scientific articles, as well as others, did not include a systematic geographical description of geysers but contained many 'scientific' versions of names in text and tables.

Unfortunately, 'the tough 1990s'[3] hindered the preparation and publication of a final monograph with the results of long-term geological and geothermal investigations in the Valley. The monograph was never published. However, in 2004, the concise scientific and popular edition was published in electronic form (Sugrobov *et al.*, 2004) and in 2009 in print form (Sugrobov *et al.*, 2009). This book represents a 'scientific' tradition in the naming of thermal features and contains a systematic description of 74 geysers and springs with names. Two maps of geyser locations based on a 1:2 000 topographic map were first published in this book, which contained approximately 50 thermal features with names, Figures 9 and 10.

Figure 8. A part of the topographic map (1:10 000) with manually written names and marks of geysers and springs, 1970s (courtesy of Viktor Sugrobov).

Table 2. Geysers and boiling springs which names were first published during 1975–2007 years.

#	ID[1]	Published names[2]	Longitude (E)[3]	Latitude (N)[3]	Status
1	0SVE	**Светлана (Svetlana, *named after S.F. Glavatskikh*)** (Semenov, 1973)	160°0′50,841″	54°29′54,196″	Disappeared in 1976
2	3AVE	**Аверий (Averiy, *named after V.V. Averyev*)** (Sugrobova *et al.*, 1989)	160°8′3,294″	54°25′58,293″	Buried in 2007
		Древний (Drevniy, *Ancient*) (Bryan *et al.*, 1991)			
3	3GLI	**Глинистый (Glinistyy, *clayey*)** (map 1:2000 1973; Sugrobova *et al.*, 1989)	160°8′13,736″	54°25′58,845″	Buried in 2007
4	3MAL	**Малютка (Malyutka, *baby*)** (Sugrobov *et al.*, 2009)	160°8′7,147″	54°26′0,432″	Buried in 2007
5	3PLO	**Плоский (Ploskiy, *flat*)** (Sugrobov *et al.*, 2009)	160°8′10,798″	54°26′0,085″	Buried in 2007
6	3SHI	**Шило (Shilo, *awl*)** (Bryan *et al.*, 1991)	160°7′49,874″	54°25′58,976″	Buried in 2007
7	3TER	**Теремок (Teremok, *small fairy-tale house*)** (Sugrobova *et al.*, 1989)	160°8′11,26″	54°26′0,444″	Buried in 2007
		Теремковый (Teremkovyy, *like a small fairy-tale house*) (Sugrobov *et al.*, 2009)			
8	3UTY	**Утюжок (Utyuzhok, *small iron*)** (Bryan *et al.*, 1991)	160°8′1,291″	54°25′58,426″	Buried in 2007
9	4BUR	Принц Буратино (Prints Buratino, *prince Buratino*) (Shteinberg *et al.*, 1976)	160°7′57,022″	54°26′13,638″	Buried in 2007
		Маленький Принц (Malenkiy Prints, *the Little Prince*) (Bryan *et al.*, 1991)			
		Буратино (Buratino, *named after the popular character of the children's book*) (Sugrobov *et al.*, 2009)			
10	4DVU	**Двухручейный (Dvukhrucheynyy, *double-streamed*)** (Sugrobov *et al.*, 2009)	160°7′53,591″	54°26′5,35″	Buried in 2007
11	4NEC	**Нечаевский (Nechaevskiy, *named after V. N. Nechayev*)** (Sugrobov *et al.*, 2009)	160°7′57,104″	54°26′11,941″	Buried in 2007
12	4NED	**Недоступный (Nedostupnyy, *unaccessible*)** (Sugrobov *et al.*, 2009)	160°7′52,816″	54°26′6,312″	Buried in 2007
		МВС (MVS, *named after the НИИ МВС – Scientific Research Institute of Multiprocessor computer systems,Taganrog)* (Karpov, 2010a)			
13	4NOV	**Новая Печка (Novaya Pechka, *new oven*)** (Bryan *et al.*, 1991)	160°7′55,84″	54°26′9,253″	Buried in 2007
14	4POD	**Подскальный (Podskalnyy, *under-the-rock*)** (Sugrobov *et al.*, 2009)	160°7′56,192″	54°26′7,891″	Buried in 2007
15	4ROM	**Ромео и Джульетта (Romeo i Dzulyetta, *Romeo and Juliet*)** (Sugrobov *et al.*, 2009)	160°7′56,132″	54°26′14,487″	Buried in 2007
16	4DZH	*(pair of boiling springs)*			Buried in 2007
17	4TEK	**Текучий (Tekuchiy, *fluid*)** (Sugrobov *et al.*, 2009)	160°7′56,954″	54°26′8,727″	Buried in 2007
		Лафет (Lafet, *gun carriage*) (Bryan *et al.*, 1991)			
		Артефакт (Artefakt, *artifact*) (Karpov, 2010a, Kiryukhin and Rychkova, 2011)			
18	4ZHA	**Жало (Zhalo, *serpent's tongue*)** (Bryan *et al.*, 1991)	160°7′55,24″	54°26′7,501″	Buried in 2007
19	4ZON	**Зонтик (Zontik, *parasol*)** (Bryan *et al.*, 1991)	160°7′56,13″	54°26′13,803″	Buried in 2007
20	5BEZ	**Безголовый (Bezgolovyy, *headless*)** (Bryan *et al.*, 1991)	160°8′11,025″	54°26′18,043″	Buried in 2007
		Жульен (Zhulyen, *named after Julien Sorel*) (Sugrobov *et al.*, 2009)			
21	5BOR	**Борода (Boroda, *beard*)** (Bryan *et al.*, 1991)	160°8′10,488″	54°26′17,969″	Buried in 2007
22	5GNO	**Гном (Gnom, *dwarf*)** (Sugrobov *et al.*, 2009)	160°8′7,525″	54°26′16,628″	Buried in 2007
23	5KRA	**Красный (Krasnyy, *red*)** (Sugrobov *et al.*, 2009)	160°8′4,876″	54°26′17,305″	Buried in 2007
24	5KRU	**Кругленький (Kruglenkiy, *round*)** (Sugrobov *et al.*, 2009)	160°8′5,964″	54°26′16,684″	Buried in 2007
		Смуглый (Smuglyy, *swarthy*) (Bryan *et al.*, 1991)			
25	5NOR	**Норка (Norka, *burrow*)** (Bryan *et al.*, 1991)	160°8′9,815″	54°26′17,511″	Buried in 2007
26	5PER	**Персик (Persik, *peach*)** (Sugrobov *et al.*, 2009)	160°8′15,983″	54°26′19,235″	Buried in 2007
		Серый Тюльпан (Seryy Tyulpan, *gray tulip*) (Bryan *et al.*, 1991)			
27	5PES	**Пещерный (Peshchernyy, *cave*)** (Sugrobov *et al.*, 2009)	160°8′5,884″	54°26′16,831″	Buried in 2007
		Раскрытый Камень (Raskrytyy Kamen, *split rock*) (Bryan *et al.*, 1991)			
28	5RYZ	**Рыжий (Ryzhiy, *red haired*)** (Bryan *et al.*, 1991) *(in the 1991 catalogue, the name in Russian is misspelled as «Ритий»)*	160°8′7,195″	54°26′16,262″	Buried in 2007
29	5SBO	**Секретарь Большого (Sekretar Bolshogo, *Bolshoy's secretary*)** (Bryan *et al.*, 1991)	160°8′10,599″	54°26′16,779″	Buried in 2007
30	5SMA	**Секретарь Малого (Sekretar Malogo, *Malyy's secretary*)** (Bryan *et al.*, 1991)	160°8′9,541″	54°26′16,169″	Buried in 2007
31	5STA	**Старик (Starik, *old man*)** (Sugrobov *et al.*, 2009)	160°8′10,46″	54°26′17,837″	Buried in 2007
32	5UST	**Устьевой (Ustyevoy, *outfall*)** (Bryan *et al.*, 1991)	160°8′2,973″	54°26′17,554″	Buried in 2007
33	6GRO	**Гротик (Grotik, *grottino*)** (Sugrobov *et al.*, 2009)	160°8′25,359″	54°26′16,755″	Active
34	6KOT	**Котлы (Kotly, *pots*)** (Sugrobov *et al.*, 2009)	160°8′26,893″	54°26′15,101″	Active
		Переливные котлы (Perelivnyye kotly, *overflow pots*) (Karpov, 2010a)			

35	6KRE	**Крепость (Krepost, *fortress*)** (Bryan *et al.*, 1991) Вифлеемский младенец (Vifleyemskiy Mladenets, *Child of Bethlehem*) (Shpilenok, 2007) Младенец (Mladenets, *newborn*) (Kiryukhin *et al.*, 2012)	160°8′25,057″	54°26′19,356″	Active
36	6POP	**Поперечный (Poperechnyy, *transverse*)** (Sugrobov *et al.*, 2009)	160°8′18,681″	54°26′20,169″	Buried in 2014
37	6PYA	**Пятиминутка (Pyatiminutka, *five minutes*)** (Sugrobova *et al.*, 1989) Примерный (Primernyy, *approximate*) (Bryan *et al.*, 1991)	160°8′25,167″	54°26′18,986″	Buried in 2014
38	6TRA	**Трамплинчик (Tramplinchik, *jump hill*)** (Bryan *et al.*, 1991)	160°8′20,407″	54°26′20,438″	Active
39	7ARK	**Арка (Arka, *Arch*)** (Bryan *et al.*, 1991)	160°8′39,857″	54°26′22,471″	Buried in 2014
40	7AVE	Аверьев (Averyev, *named after V.V. Averyev*) (Sugrobova, 1982) **Аверьевский (Averyevskiy, *named after V.V. Averyev*)** (Sugrobova *et al.*, 1989) Аверий (Averiy, *named after V.V. Averyev*) (Bryan *et al.*, 1991)	160°8′32,123″	54°26′19,296″	Active
41	7BAS	**Бастион (Bastion, *bastion*)** (Sugrobov *et al.*, 2009) Застенок (Zastenok, *torture-chamber*) (Bryan *et al.*, 1991)	160°8′29,126″	54°26′17,229″	Active
42	7CHP	**Чёрная Пасть (Chërnaya Past, *Black Mouth*)** (Bryan *et al.*, 1991) – *see note #6*	160°8′37,748″	54°26′20,702″	Buried in 2014
43	7CHS	**Чёрное Сердце (Chërnoye Serdtse, *Black Heart*)** (Bryan *et al.*, 1991) – *see note #6*	160°8′38,76″	54°26′21,38″	Buried in 2014
44	7GOS	**Гоша (Gosha, *GOSA*)** – *see note #7* (Bryan *et al.*, 1991)	160°8′29,299″	54°26′17,962″	Active
45	7KOR	**Коричневый (Korichnevyy, *brown*)** (Sugrobov *et al.*, 2009)	160°8′40,293″	54°26′23,45″	Buried in 2014
46	7KOT	**Котегей (Kotegey, *from the 'qualitative theory of geysers'*)** (Merzhanov *et al.*, 1973)	160°8′31,984″	54°26′19,591″	Dormant
47	7KRA	**Красавчик (Krasavchik, *dandy*)** (Nechayev, 2000; Nechayev, 2007)	160°8′34,502″	54°26′20,546″	Active
48	7KUZ	**Кузнечик (Kuznechik, *grasshopper*)** (Bryan *et al.*, 1991)	160°8′29,999″	54°26′18,237″	Active
49	7MAR	**Мартышка (Martyshka, *Monkey Face)*** – *see note #8* (Leonov, 2012a) 'Golden', 'Smoking Monkey' (Bryan *et al.*, 1991) 'Monkey Face' (Hobart, 1991)	160°8′30,077″	54°26′17,763″	Active (?)
50	7MOY	**Мойдодыр (Moydodyr, *named after the popular character of the children's book*)** (Bryan *et al.*, 1991)	160°8′37,324″	54°26′20,852″	Active
51	7SAM	**Самозванец (Samozvanets, *impostor*)** (Nechayev, 2000; Nechayev, 2007)	160°8′34,158″	54°26′20,553″	Active
52	7SKO	**Сковородка (Skovorodka, *frying pan*)** (Leonov, 2012a; Leonov, 2012b) *(on the VII thermal area)*	160°8′35,57″	54°26′21,942″	Buried in 2014
53	7SPO	**Спокойный (Spokoynyy, *calm*)** (Sugrobov *et al.*, 2009) 'Pink Stone' (Bryan *et al.*, 1991)	160°8′38,81″	54°26′22,45″	Buried in 2014 (?)
54	7TRA	**Травяной (Travyanoy, *grassy*)** (Sugrobov *et al.*, 2009)	160°8′42,107″	54°26′21,284″	Active
55	7UST	**Устиний (Ustiniy, *named after T.I. Ustinova*)** (Bryan *et al.*, 1991)	160°8′39,49″	54°26′20,777″	Buried in 2014
56	7ZAM	**Замкнутый (Zamknutyy, *enclosed*)** (Bryan *et al.*, 1991)	160°8′32,108″	54°26′19,07″	Active
57	7ZME	**Змейка (Zmeyka, *little snake*)** (Sugrobov *et al.*, 2009)	160°8′40,253″	54°26′23,41″	Buried in 2014
58	8IVA	**Иванушка (Ivanushka, *a fairy-tale character Ivanushka*)** (Sugrobov *et al.*, 2009)	160°9′50,79″	54°26′40,28″	Active
59	8KAL	**Каляевский (Kalyayevskiy, *named after V.S. Kalyaev*)** (Leonov, 2012a, Leonov, 2012b)	160°9′54,85″	54°26′39,49″	Buried in 2014
60	8VKH	**Верхний Хлоридный (Verkhniy Khloridnyy, *upper chloride*)** (Sugrobov *et al.*, 2009)	160°10′9,38″	54°26′49,97″	Buried in 2014
61	—	Прилежный (Prilezhnyy, *diligent*) (Shteinberg *et al.*, 1981)	Unknown	Unknown	Unknown
62	—	Неразведённый (Nerazvedënnyy, *undiluted*) (Bryan *et al.*, 1991)	Unknown	Unknown	Buried in 2007
63	—	Двойник (Dvoynik, *twin*) (Bryan *et al.*, 1991)	Unknown	Unknown	Buried in 2007
64	—	Сюрприз (Syurpriz, *surprise*) (Bryan *et al.*, 1991)	Unknown	Unknown	Buried in 2007
65	—	Сорок Два (Sorok Dva, *fourty two*) (Bryan *et al.*, 1991)	Unknown	Unknown	Unknown
66	—	Пёстрый (Pëstryy, *variegated*) (Bryan *et al.*, 1991)	Unknown	Unknown	Unknown
67	—	Виталий (Vitaliy, *named after V.A. Nikolayenko*) (Bryan *et al.*, 1991)	Unknown	Unknown	Unknown
68	—	Сковородка (Skovorodka, *frying pan*) (Sugrobov *et al.*, 2009) *(on the IV thermal area)*	Unknown	Unknown	Buried in 2007

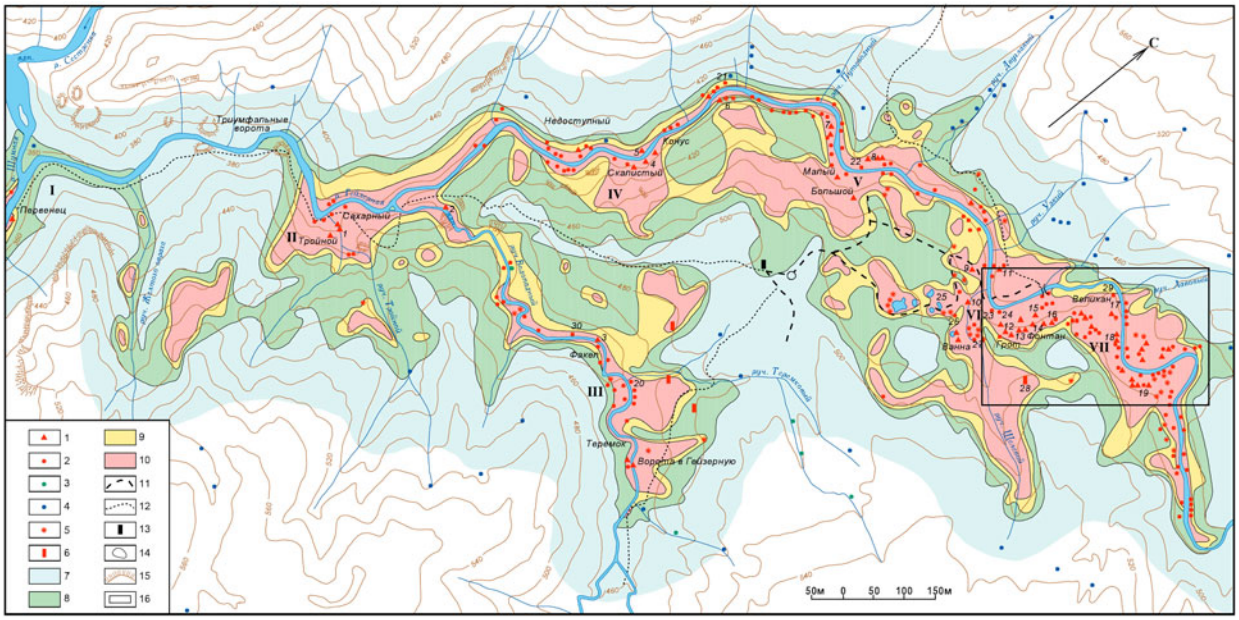


Figure 9. Map of the location of geysers from Sugrobov *et al.*, 2004; 2009.

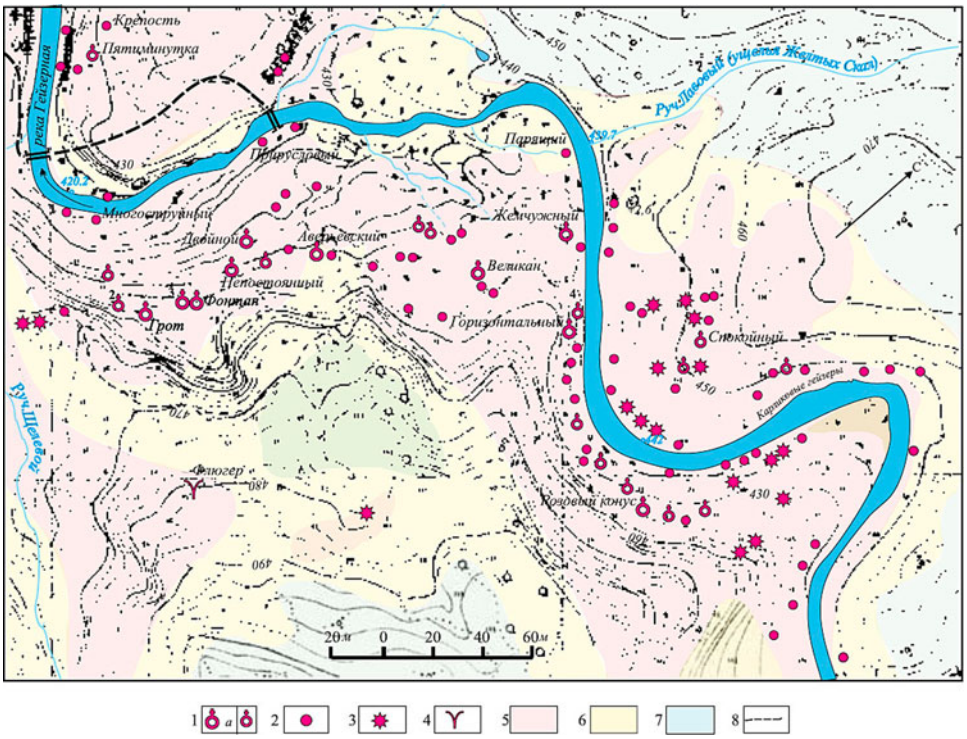


Figure 10. Map of the VII thermal area from Sugrobov *et al.*, 2004; 2009.

~~contrast~~, the oral tradition of naming thermal features continued due to the nonstop stream of unofficial tourists and official visitors in the Valley. 'Tourist' names did not always coincide with 'scientific' names. Nikolayenko, a permanent employer of the Kronotsky Reserve in the Valley of Geysers from 1970 until the 1990s, became the keeper of this tradition. This tradition was never documented until 1991, except its initial period in the chapter in the book of Semenov (1973) and simple tourist maps (Semenov, 1974; 1975). No official guidebook or popular edition about the Valley was published in the Soviet era after Semenov's book possibly because the Valley was officially closed to tourists beginning in 1976.

In 1991, visiting Kamchatka became possible for foreigners. Six members of the GOSA from Yellowstone National Park, USA visited the Valley on 1–8 July 1991 and created a thorough description (T. Scott Bryan, Bob Colvin, Martha Fenimore, Jack Hobart, John Rinehart and Bill Warnock). The expedition was led by Bryan, the author of many popular guidebooks related to the Yellowstone geysers.

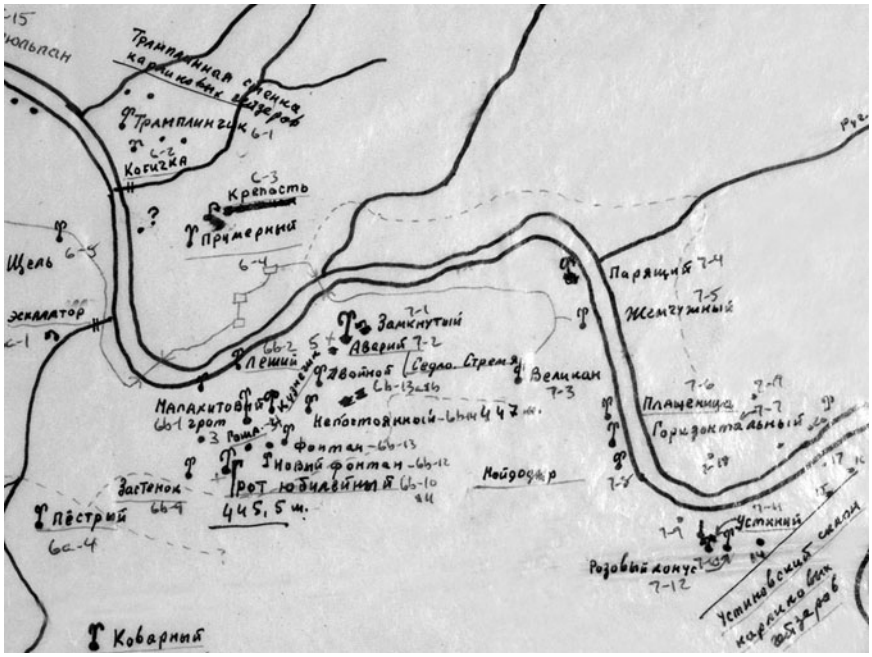


Figure 11. The draft of the map of the Valley of Geysers prepared by Vitaly Nikolayenko for the GOSA team on the basis of the 1:2000 topographic map (a fragment from 1991) (courtesy of T. Scott Bryan, photo by Jack Hobart).

The Americans were invited by Sergey Alekseev, the director of the Kronotsky Reserve, and guided by Nikolayenko, who had shown and described the thermal features of the Valley to them.

The GOSA special report about the expedition contains 104 numbered thermal features, although several of them are not localized (Bryan *et al.*, 1991). The report included 73 geysers and springs with names that were known before the expedition; the lists of thermal features in (Bryan *et al.*, 1991) and (Sugrobov *et al.*, 2009) partially differ. In addition, fourteen thermal features in the GOSA report have names coined by Nikolayenko or by the Americans during the expedition.

The report is supplemented by a map of geyser locations based on a 1:2 000 topographic map. The map contains 82 geysers and springs with names. A draft of this map was initially drawn in Russian by Nikolayenko, and then translated for publication in English by Bryan, Figures 11 and 12.

The report, prepared by Bryan and his colleagues, became the most comprehensive catalogue of geysers and springs of the Valley of Geysers for many years (at least, until the publication of the book of Sugrobov *et al.*,

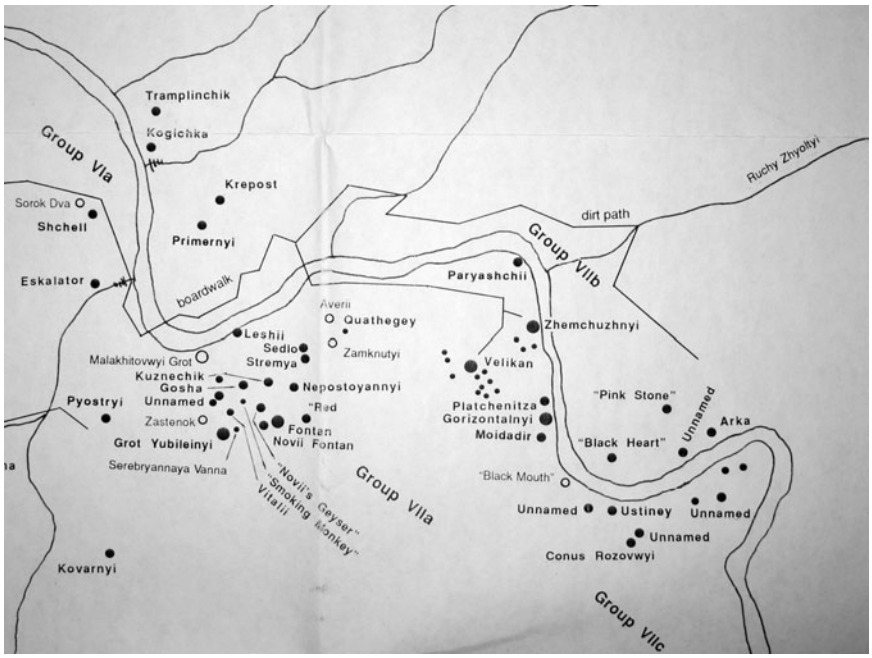


Figure 12. The map of the Valley of Geysers that was published in the GOSA special report (a fragment from 1991) (Bryan *et al.*, 1991).

2004; 2009) and the first one (and still the only one) published in English. This book was an impressive achievement for a one-week expedition. As a result, the English-speaking community became aware of the second largest geyser field in the world.

At the same time, the Americans did not know about the work being done by Russian researchers of Sugrobov's team. The Russian scientists were not involved in preparation of the report and their working maps and publications were not considered. As a result, the GOSA report documented mainly the oral 'tourist' tradition, presented by Nikolayenko and did not consider some previously published 'scientific' names. If the collaboration between Russian and American researchers was established in 1991, it surely would have led to more detailed descriptions of the thermal features and improved cartography in the report.

In addition to the GOSA report, the 'tourist' tradition of naming was also documented in books of Nechayev (2000; 2007). These richly illustrated books contain systematic descriptions and colourful photos of 40 geysers and springs as well as simple maps of the location of the thermal features in thermal areas. The first book (2000) was prepared with the direct participation of Nikolayenko.

Thus, the second stage of mapping and naming of thermal features continued for more than 30 years and was based on large-scale maps of the territory. Minor geysers, springs and other thermal features (mudpots, hot pools, steam vents) were named by researchers and tourists without any regulation as well as other tourist attractions (like rocks, creeks, waterfalls, etc.). The number of geysers and boiling springs with documented names in systematic catalogues exceeded 70 (Bryan *et al.*, 1991; Sugrobov *et al.*, 2004; 2009). The total number of geysers and boiling springs with documented names published during 1941–2007 reached 116, although the exact location of ten of them is still unknown, see Tables 1 and 2. Due to the parallel evolution of the two naming traditions, approximately one-third of all thermal features had more than one name at the end of the second stage.

During 1991–2007, the landscape and thermal features were quite stable, and no new active naming was documented. Sugrobov and Sugrobova left Kamchatka in the beginning of the 1990s. Nikolayenko left the Valley in the 1990s and devoted himself to the photography and research of the brown bears; he was killed by a bear in 2003. Ustinova died in Vancouver, Canada in 2009. Her death was the end of an era.

Since 2009: A time of 3-D documents

A huge landslide severely damaged the Valley of Geysers on 3 June 2007. About one-half of all geysers and springs were buried by the landslide or flooded by the landslide-dammed lake and later buried with alluvium that filled the lake (Leonov and Leonov, 2014). The volume of the landslide reached 21 million cubic metres (Dvigalo and Melekestsev, 2009). It is no doubt the largest landslide in Kamchatka on record and one of the largest in Russia. This shocking natural disaster inspired a new wave of interest in the Valley and its research. For example, in 2008 during a national contest, the Valley of Geysers was voted as one of the 'Seven Wonders of Russia.'

After the investigation of the 2007 landslide, several researchers alerted in their articles that new landslides are possible in the Valley in future without any practical possibility to prevent them (Dvigalo and Melekestsev, 2009; Leonov, 2007). In 2009, an international conference 'GeyserValley 2009' was organized to discuss methods for the digital preservation of information about the Valley.[4] After the conference, a project on the virtual modelling of the Valley of Geysers began.[5] Three field expeditions were organized during 2009–2011 to collect data about the surviving thermal features and to prepare the first version of the 3-D model (Leonov *et al.*, 2010; 2011).

Just prior to the conference, the first high-resolution multispectral image of the Valley and the neighbouring area became available (GeoEye-1, 0.5 m, 06 September 2009). A sponsor of the conference, ScanEx, purchased 100 sq. km of satellite imagery and later the full frame (more than 300 sq. km) was provided to the project by the GeoEye Foundation. The image was precisely geo-referenced during the field expedition in 2009 with the use of a dual-frequency geodetic GPS receiver. Specialists of ScanEx also created a digital elevation model of the territory based on a pair of 2007 panchromatic images (CartoSat, 2.5 m, 19 September 2007). This satellite data became the basis for the virtual 3-D model of the territory (3-D document), Figure 13.

To develop a virtual model of the Valley of Geysers, it was necessary to prepare a systematic description of thermal features and other physical features and to overcome discrepancies between the 'scientific' and 'tourist' traditions of naming. A thorough investigation of the literature was performed, including the comparison of old maps with the current landscape using the digital 3-D model. As a result, a catalogue of surviving geysers, boiling springs and other features was prepared and published in 2012 (Leonov, 2012a; 2012b). One of the major advances of the new catalogue was the compilation of a unified list of thermal features and other features and the selection of a primary name for each thermal feature for further use. Additionally, for the first time, maps indicating the location of the geysers in geographic coordinates were published. Later, this

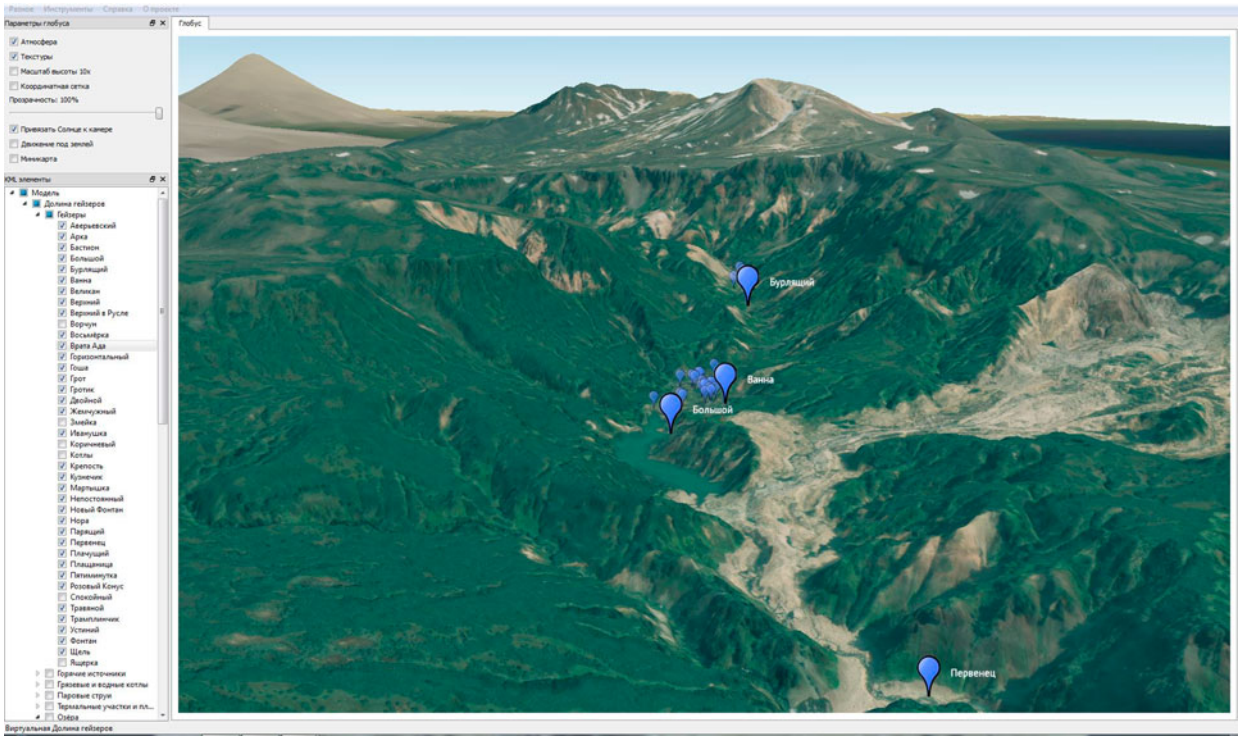


Figure 13. The interactive application based on a 3-D model of the territory of the Valley of Geysers.

information was used in other publications to prepare maps of the location of the geysers (Zavadskaya *et al.*, 2014; 2015).

The predictions of the scientists came true sooner than anticipated. On 4 January 2014, another huge landslide occurred in the upper reaches of the Geyzernaya River. This landslide caused a powerful mudflow that damaged many thermal features downstream along the river course (Leonov, 2014). In September 2014, aerial photography of the territory along the Geyzernaya River was performed by the specialists of the Kronotsky Reserve. Based on this aerial photography, a digital 3-D model of the territory and maps of the geyser locations were updated, Figure 14.

Old maps were compared with the actual landscape on the basis of the 3-D model to analyse the location of the buried thermal features, Figure 14. This comparison proved that some of the buried geysers and boiling springs

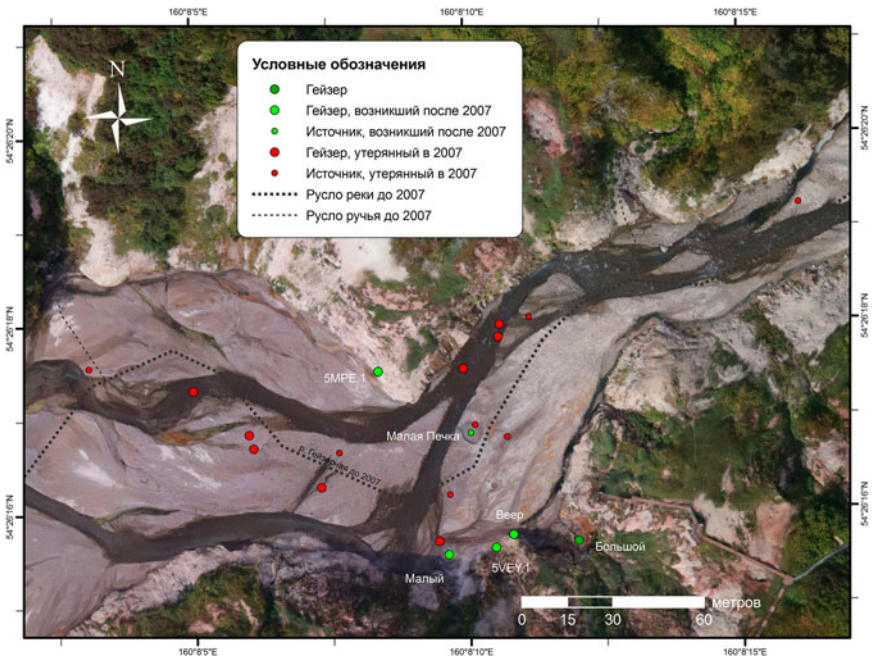


Figure 14. Geo-referenced digital map of the V thermal area (Leonov, 2017).

were restored near their previous locations, see for example, 'Малый' (Malyy (*small*), 5MAL) and 'Малая Печка' (Malaya Pechka (*small oven*), 5MPE) in Figure 14.

Major changes in landscape morphology after the landslides caused the formation of new geysers and boiling springs. These geysers began to receive new names, Table 3. Moreover, a new geyser arose in the Uzon Caldera in 2008; this event was probably connected with the 2007 landslide in the Valley (see 0SHA in Table 3).

The 2007 and 2014 events also caused changes in the behaviour of many existing thermal features. For example, after the 2007 landslide, the Krepost (*fortress*) geyser (6KRE) on a right bank of the Geyzernaya River started to erupt regularly. This change in the behaviour prompted an attempt to provide it with a new name, Table 2. New names were offered for Paryashchiy (*steaming*) geyser (7PAR) and unnamed geyser 7ROZ.2, Table 1.

Thus, the 2007 landslide was a trigger for the start of a new stage of mapping and naming of geysers and springs. The year 2009 can be considered a starting point of this stage, since the first high-resolution multispectral satellite image was created and geo-referenced digital 3-D modelling of the territory was started as well as a new wave of studies regarding the systematization of thermal features. Geysers and boiling springs with documented names that were first described and named after 2007 are presented in the Table 3.

In 2017, a new catalogue of geysers and springs was published (Leonov, 2017). This catalogue contains more than 150 geysers and springs, both existing and buried. The catalogue contains many unique historical and modern photographs and aims to create a durable bridge between the past and future of cartography and toponymy in the Valley and a basis for further research.

Development of the tools to measure geyser activity

The stages of development of cartography and toponymy correlate well with the development of tools to measure geyser activity. An analysis of this correlation reveals the dramatic role of personal factors and force major circumstances (such as the state disintegration or catastrophic natural disasters) on the evolution of research tools and methods.

The start of routine research in the early 1970s led not only to creation of large-scale maps (and a new stage of naming thermal features) but also to the application of a new technology for measuring the activity of the geysers. For example, the water level gauges that were installed on fifteen geysers enabled accurate automatic measurements of their activity, Figure 15. The automatic measurement of geyser activity with the use of water level gauges continued regularly until the early 1990s (for the Velikan Geyser); the sporadic use of water level gauges continued to the late 1990s. In 1974–1975, year-round monitoring was organized, although a heroic effort was required in the everyday maintenance of the water level gauges.

Political turbulence in the Soviet Union at the end of the 1980s led to 'the tough 1990s' and decline of regular research in the Valley but at the same time it coincided with the implementation of a new technology for the measurement of geyser activity. In 1988, Valery Droznin and Igor Kalyaev started to develop their system based on contact closure. Two electrodes were placed into the geyser outflow channel in such a way that contact closure occurred only during the outflow and eruption stages during geyser operation, Figure 16. This system worked successfully for more than fifteen years. These data were collected in real-time on a personal computer in a house of a scientist in the headquarters of the Valley of Geysers (using wires from geysers to the house). The system was stopped only in 2006 due to the absence of financing.

The landslide of 2007 stimulated a new wave of research in the Valley that attracted a new generation of researchers with new tools and methods. Alexey Kiryukhin started to use temperature loggers for the measurement of geyser activity beginning in 2007. The loggers were installed both in the outflow channel of the geyser and inside the vent. An example of collected data is presented in Figure 17.

After the 2014 landslide, Alexander Belousov and Marina Belousova started widely using automatic long-term videotaping for the documentation of geyser activity. Manual processing is required to register the activity but at the same time this method is simpler in implementation than automatic detectors.

Conclusions

An analysis of the history of mapping and naming of thermal features in the Valley of Geysers shows that the development of the toponymy of this area was limited mainly by the quality of the cartographic base that was accessible to researchers. The use of manual maps or diagrams enabled the documentation of more than 40 geysers and boiling springs (1973); the publication of large-scale topographic maps in 1975 resulted in the documentation of approximately one hundred thermal features by 1991. Catastrophic landslides in 2007 and 2014 damaged the Valley severely and more than one half of the thermal features were destroyed. The use of high-resolution data by remote sensing since 2007 provided a base for the further development of the

Table 3. Geysers and boiling springs that were described and named after 2007.

#	ID[1]	Published names[2]	Longitude (E)[3]	Latitude (N)[3]	Status
1	0SHA	Мутный (Mutnyy, *turbid*) (Droznin, 2009) **Шаман (Shaman, *shaman*)** (Karpov, 2010b)	160°0′43,865″	54°29′58,534″	Active
2	2NOV	**Новый (Novyy, *new*)** (Leonov, 2012a)	160°7′39,764″	54°25′55,965″	Unknown
3	5VEY	**Веер (Veyer, *hand fan*)** (Zavadskaya *et al.*, 2015)	160°8′10,692″	54°26′15,735″	Active
4	5VEY.1	гейзер за углом (geyzer za uglom, *geyser around the corner*) (Leonov, 2017) Андрей (Andrey, *named after A.V. Leonov*) (Belousov and Belousova, 2017)	160°8′10,371″	54°26′15,599″	Active
5	—	Владимир (Vladimir, *named after V.L. Leonov*) (Belousov and Belousova, 2017)	160°8′10,16″	54°26′15,48″	Active
6	6MAL	**Малыш (Malysh, *baby*)** (Belousov and Belousova, 2017)	160°8′18,953″	54°26′20,3″	Active
7	7RAZ	**Разрушенный (Razrushennyy, *destroyed*)** (Leonov, 2012a)	160°8′43,07″	54°26′21,94″	Buried in 2014
8	7RZV	**Розовый (Rozovyy, *pink*)** (Leonov, 2012a)	160°8′38,587″	54°26′22,786″	Buried in 2014
9	7VCH	**Ворчун (Vorchun, *grumbler*)** (Leonov, 2012a)	160°8′39,03″	54°26′22,26″	Buried in 2014
10	7VOR	**Воронка (Voronka, *funnel*)** (Leonov, 2012a)	160°8′38,38″	54°26′21,65″	Buried in 2014
11	8YAS	**Ящерка (Yashcherka, *lizard*)** (Leonov, 2012a)	160°9′29,467″	54°26′31,613″	Buried in 2014

Note 1: In the column 2, the ID is shown in accordance with the catalogue (Leonov, 2017).

Note 2: In the column 3, each name is given in its original form in Russian, then transliterated using BGN/PCGN system and translated. The literature source is shown where the name was first published. The most used names (if any) are written in **bold**.

Note 3: In columns 4 and 5, the coordinate system WGS84 is used. Coordinates are calculated on the basis of the geo-referenced satellite imagery, aerial photographs and digital 3-D model of the territory (Leonov, 2017).

Note 4: These thermal features (5MAL and 5MPE) were flooded in 2007 by the landslide-dammed lake, but stayed active underwater (approximately 8–9 and 15–16 metres under the water level accordingly). After the formation of the alluvial plain in place of the lake, 'new' thermal features were formed on the surface of the plain close to the previous locations of 5MAL and 5MPE, as can be observed on the map in Figure 14.

Note 5: This geyser (7ROZ.2) was partially buried in 2014 by the mudflow, but stayed active and now erupts from another vent.

Note 6: These boiling springs were named by Americans during their expedition in 1991 as 'Black Mouth' and 'Black Heart' accordingly. Their names in Russian are the direct translations of their English names.

Note 7: This geyser was named after GOSA by V. Nikolayenko during the GOSA expedition in 1991. Its name in Russian – 'Гоша' (Gosha) – sounds similar to GOSA.

Note 8: Several names for this geyser were offered by Americans during their expedition in 1991. In the catalogue (Leonov, 2012a) it was offered to use the name 'Monkey Face' in English and 'Мартышка' (Martyshka, *monkey*) in Russian for this geyser (because the direct translation of the 'Monkey Face' in Russian sounds quite strange and not appropriate to use).

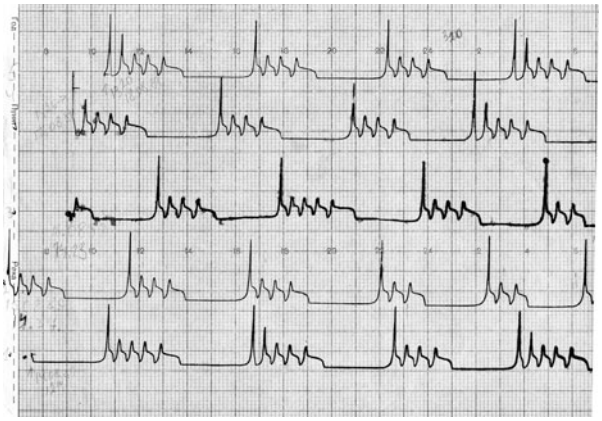


Figure 15. Raw data of the water level gauge 'Valday.' Velikan (*giant*) geyser activity, August 13–18, 1989. Time increases from right to left, 1 big square is 1 hour. Courtesy of Viktor Sugrobov.

toponymy that is now in its initial phase. For the moment, there are approximately 50 active geysers and boiling springs with personal names in the Valley.

The cartography and toponymy in the Valley of Geysers evolved gradually, although with a regrettable under-documentation in the late Soviet Union timeframe (1970–1991). The classification of large-scale maps of the Valley was evidently excessive and led to confusion. The maps were used by researchers but unavailable to the general public and researchers could not publish them. The closure of the Valley to tourism in 1976 was no doubt necessary to save its natural attractions but at the same time it eliminated the formal reason to publish information about it. No well-illustrated guidebook with a systematic description of thermal features and no large-scale maps of the Valley were ever published during the Soviet time, despite its great popularity.

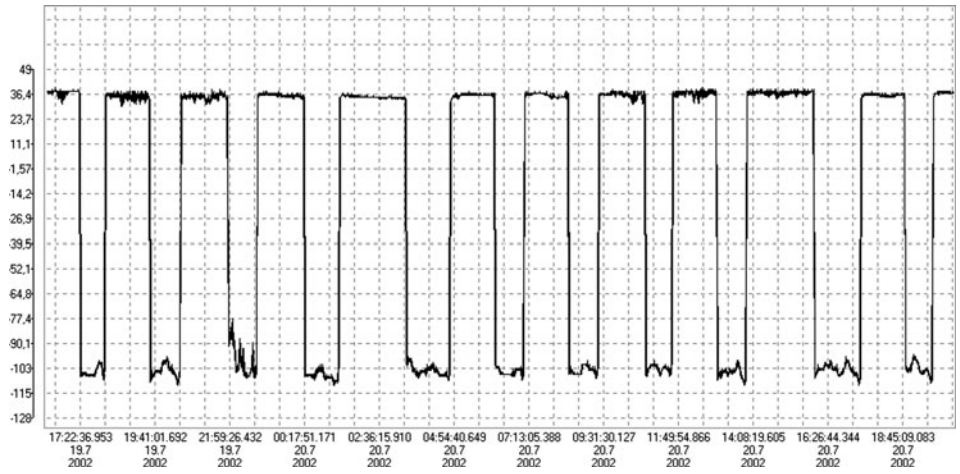


Figure 16. An example of data obtained by a sensor based on contact closure. Troynoy (*triple*) geyser, 2002. Courtesy of Valery Droznin.

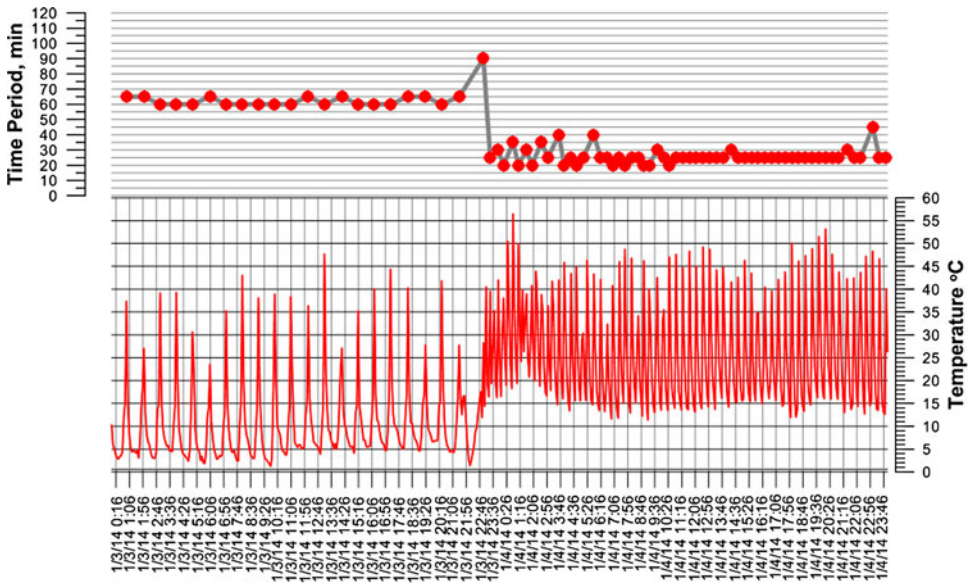


Figure 17. An example of data obtained by a temperature logger for the Bolshoy (*large*) geyser, 2014. The change in the geyser activity after the mudflow of January 3, 2014 is clearly seen on the graph (Kiryukhin, 2015; Kiryukhin, 2016).

Catastrophic landslides in 2007 and 2014 inspired a new wave of interest in the Valley including the further development of its cartography and toponymy. In 2017, a new catalogue was published in a manner that carefully considers all previous publications. This catalogue contains description of more than 150 geysers and springs and more than 500 historical and modern photographs. This catalogue was prepared with the participation of Russian researchers and members of the 1991 American expedition to overcome existing confusion and provide a durable basis for the further research in more open and collaborative world.

The rapid development of small-scale automatic loggers and computer graphics tools (for example, virtual globe platforms such as Cesium) provide good opportunities for the future development of the measurements of geyser activity and 3-D visualization in the Valley of Geysers. Our hope is the reestablishment of a real-time monitoring system based on temperature loggers that connects to the Internet using a satellite channel and the visualization of this real-time telemetry information on the basis of the 3-D model of the territory with free Internet access.

Notes

1. Velikan (*giant*), Fontan (*fountain*), Troynoy (*triple*), Bolshoy (*large*), Zhemchuzhnyy (*pearl*), Pervenets (*firstborn*), and Bolshaya Pechka (*large oven*) (Ustinova, 1946b).
2. Vladimir Belousov, Vladimir Voronkov, Elena Grib, Valery Droznin, Vladimir Leonov, Victor Sugrobov, Nina Sugrobova, Yuri Khatkevich and others (Sugrobov et al., 2009: 10).
3. The first decade after the disintegration of the USSR in 1991 was characterized by a strong economic downturn and decrease in the standard of living for many Russians.
4. Supported by the Russian Foundation for Basic Research, research project No. 09-07-06042-r, 2009.
5. Supported by the Russian Foundation for Basic Research, research project No. 10-07-00407-a, 2010-2012.

Acknowledgements

The author is grateful to Viktor Sugrobov and T. Scott Bryan who read the manuscript and provided valuable comments, and to Genean Dunn who kindly edited and corrected the English text.

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