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**A NEW SUBSPECIES OF *BEMBIDION SANATUM* (COLEOPTERA:
CARABIDAE) ENDEMIC TO THE MENDELEEV VOLCANO
(KUNASHIR ISLAND, RUSSIA)**

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Summary. *Bembidion (Peryphanes) sanatum iwanai* ssp. n. is described from the solfatara fields of the Mendeleev Volcano (Kuril Archipelago: Kunashir Island). It slightly differs from the nominative subspecies by body proportions, as well as the relatively narrow external intervals of the elytra and their microsculpture, yet showing stable distinctions in endophallus armature (basal part of lamina 1 is rounded, vs. angular in the nominative subspecies) and in the spermatheca duct (5–6 convolutions, vs. 7–8 in the nominative subspecies). Endemism of insects on the island's large volcanic massifs of Kunashir Island is discussed.

Key words: carabid beetles, solfatara fields, volcanism, endemism, Russian Far East.

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Резюме. С сольфатарных полей вулкана Менделеева (о-в Кунашир, Курилы) описывается новый подвид жуелици: *Bembidion (Peryphanes) sanatum iwanai* ssp. n. Он незначительно отличается от номинативного подвида пропорциями тела, а также относительно узкими наружными промежутками надкрылий и их микроскульптурой, но демонстрирует устойчивые различия в вооружении эндофаллуса (базальная часть пластинки 1 округлая, у номинативного подвида угловатая) и строения канала сперматеки (5–6 оборотов против 7–8 у номинативного подвида). Обсуждается эндемизм насекомых крупных вулканических массивов острова Кунашир.

INTRODUCTION

The Mendeleev Volcano (889 m a.s.l.) is one of the four active volcanoes on Kunashir Island. In terms of geomorphology and geochemistry, this volcano is the most explored in the Kuril Archipelago (Abdurakhmanov *et al.*, 2004). It emerged as the result of an eruption in the Middle Pleistocene (200–230 thousand years ago), while its modern looks have become formed due to the relatively recent, Holocene eruptions some 36 and 2.5 thousand years ago (Razjigaeva *et al.*, 2011; Zharkov, 2014). A group of solfatara fields confined to the circular

cracks of the volcano's cone was formed in the Late Holocene (Lebedev *et al.*, 1980). These fields remain considerably active even at present, with the temperatures in the solfatara fields over the period of observations in the 20th century often exceeding 100°C. Initial landscapes are thereby destroyed as the result of these activities, new or modified habitats arising in their stead.

In a zoological aspect, solfatara fields belong to the least explored landscapes of the Kunashir Island. In particular, publications concerning the fauna of carabid beetles are scarce. Thus, Konakov (1956) recorded three species or subspecies from the solfatara fields of the Mendeleev Volcano: *Cicindela sachalinensis* A. Morawitz, 1862, *Cylindera elisae* (Motschulsky, 1859), and *Carabus blaptoides rugipennis* Motschulsky, 1861. One of these was later described as an endemic taxon: *Cylindera elisae kunashirensis* Pütz et Wiesner, 1994 (Pütz & Wiesner, 1994). Kryzhanovskij *et al.* (1975) reported five species from the Mendeleev Volcano: *Nebria (Reductonebria) ochotica* R. Sahlberg, 1844, *Bembidion (Ocydromus) dolorosum* (Motschulsky, 1860), *B. (Peryphanes) sanatum* Bates, 1883, *Pterostichus (Euferonia) thunbergi* A. Morawitz, 1862, and *Dromius (Klepterus) prolixus* Bates, 1883. As our studies show (Makarov *et al.*, 2020), only five carabid species are capable of successfully surviving and breeding on the solfatara fields: *Cicindela sachalinensis*, *Cylindera elisae*, *Bembidion dolorosum*, *B. sanatum*, and *Poecilus samurai* (Lutshnik, 1916), whereas the others penetrate them only occasionally.

A study of additional specimens of *Bembidion sanatum* occurring on the Mendeleev Volcano has allowed us to reveal that they belong to a separate subspecies described hereafter.

MATERIAL AND METHODS

Material taken on the Kunashir Island, Mendeleev Volcano: Northeastern solfatara field, the source and upstream of Kislaya River.

Beetles were examined under a MBS-1 stereoscope, the slides studied under a Zeiss Axio Scope.A1 microscope. For preparing the slides, the aedeagi of some male specimens were consistently kept in 10% KOH (24 h.), 4% acetic acid (5 min.) and cold water (5 min.), and then mounted with Hoyer fluid.

Examining specimens deposited in the Federal Scientific Center of East Asia Terrestrial Biodiversity, Far Eastern Branch of the Russian Academy of Sciences, Vladivostok (FEB), the Zoological Institute of the Russian Academy of Science, St. Petersburg (ZISP), Moscow State Pedagogical University, Moscow (MPU), the Zoological Museum of the Moscow State University, Moscow (ZMMU).

Photographs were taken with a Canon EOS 5D Mark III camera with a Canon MP-E 65 mm macro lens, male genitalia were photographed with a Canon EOS 6D camera attached to a Zeiss AxioScope.A1 microscope. In both cases, the extended focus technique was used. All pictures were processed using Zerene Stacker software.

The nomenclature of the sclerites of the male internal sac follows Belousov and Sokolov (1996), as well as Neri and Vigna Taglianti (2010). The measurements as follows: AL – aedeagus length; EL – greatest length of elytra; EW – greatest width of elytra; HL – length of head, measured along the median line from fore margin of clypeus to rear edge of the temples; HW – greatest width of head; M – arithmetic mean; PA – width of pronotal apex; PB – width of pronotal base; PLm – length of pronotum, measured along the median line; PLt – greatest length of pronotum; PW – greatest width of pronotum; TL – total body length without labrum (from anterior margin of clypeus to the elytral apex along the suture).

TAXONOMY

Bembidion (Peryphanes) sanatum iwanai Makarov et Sundukov, ssp. n.

<http://zoobank.org/NomenclaturalActs/AB33AD02-E50F-4FBC-BC41-A0F9533AC812>

Figs 1–2, 5–6, 9–10, 13–14, 17–19, 23–25, 28–29

TYPE MATERIAL. Holotype – ♂, **Russia**: Kunashir Island, valley of Kislaya River, below hot springs, 18.VI 2011, leg. A. Matalin (ZISP). Paratypes: the same label as the holotype, 1 ♀ (MPU); Kunashir Island, Mendeleev Volcano, source of Kislaya River, below the solfatara field, 3.VIII 2016, 1 ♂, 1 ♀, leg. Yu. & L. Sundukov (FEB); the same locality but 22.IX 2016, 15 ♂, 17 ♀, leg. Yu. Sundukov (ZISP, ZMMU, MPU, FEB); the same locality but 15.VII 2017, 6 ♂, 9 ♀, leg. Yu. & L. Sundukov (FEB).

COMPARATIVE MATERIAL. *Bembidion (Peryphanes) sanatum sanatum* Bates, **1883. Japan**: Honshu Island, Mount Hikageyama Jyoushu, Gunma Pref., 18.IX 1993, 2 ♂, 2 ♀, leg. S. Morita (ZISP, MPU).

Measured: 8 ♂, 7 ♀; genital prepate: 5 ♂; 5 ♀.

DESCRIPTION. Body moderately convex; TL = 5.1–6.3 mm, EW = 2.2–2.7 mm.

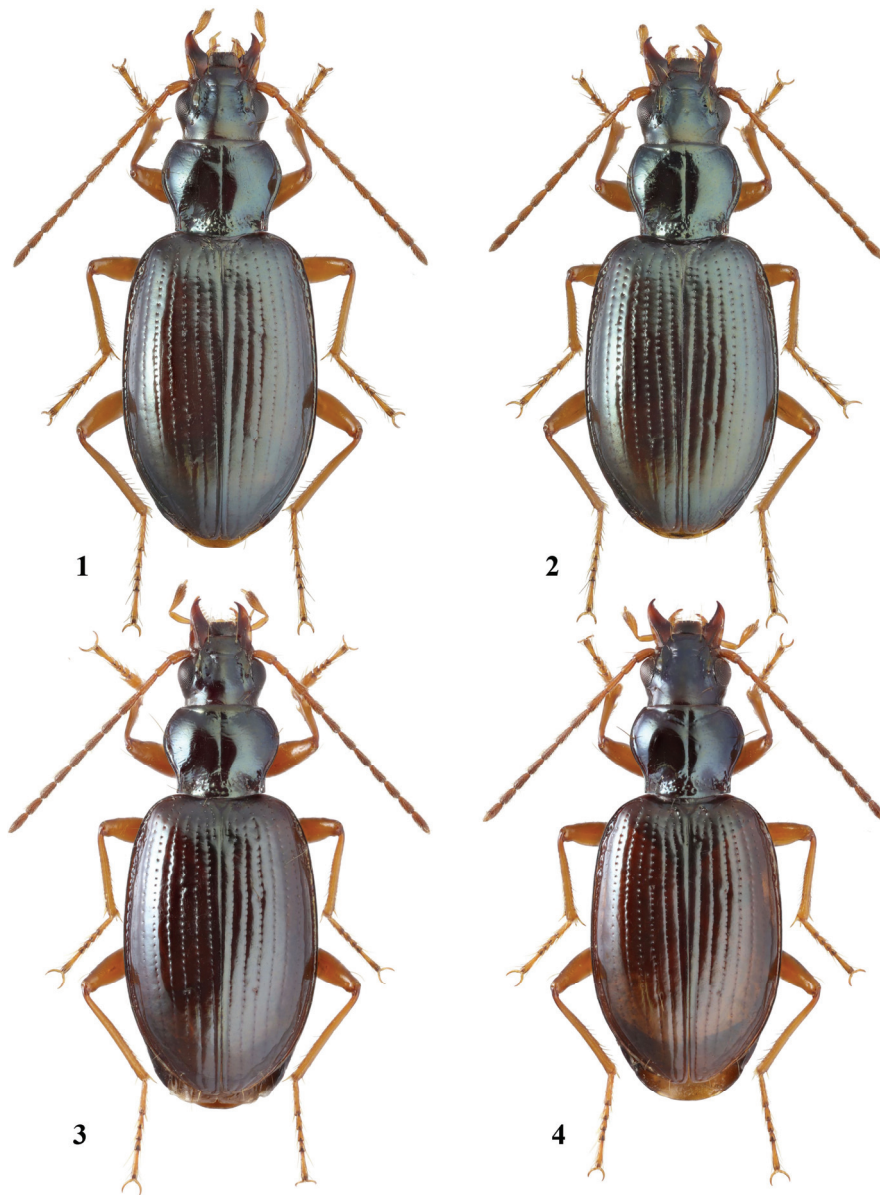
Head and pronotum dark brown, with intense blue shine; elytra resin-brown or brownish with slightly darkened apices; mandibles brown, with blackened apices and middle part; palps, antennae and legs pale brown; ventral surface black or tar-brown (Figs 1, 2).

Dorsal surface shiny, elytral microsculpture (better visible in females) formed by thin transverse lines (Figs 9, 10), barely visible at x56. Head and pronotum with scattered fine punctures; on the elytra, only striae are punctured.

Basic measurements (30 specimens): HW 1.08–1.22, M 1.13; HL 0.83–0.97, M 0.91; PA 0.98–1.12, M 1.05; PW 1.36–1.62, M 1.46; PB 1.03–1.22, M 1.13; PLt 1.13–1.35, M 1.23; PLm 1.09–1.21, M 1.16; EW 2.28–2.60, M 2.42; EL 3.43–3.98, M 3.66; TL 5.43–5.94, M 5.65.

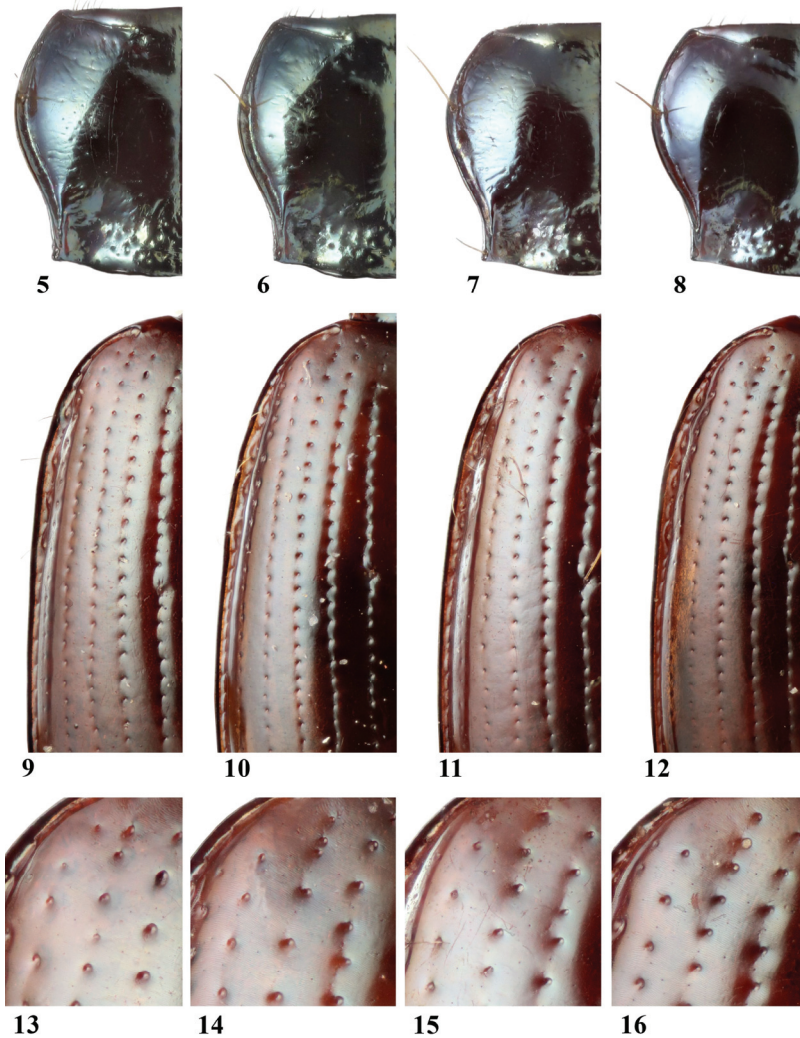
Head normal, moderately convex, slightly transverse (HW/HL = 1.17–1.33, M 1.26). Eyes small, moderately convex. Antennae slender, long, 0.85–0.93 times as long as elytra in both sexes; 2nd antennomere shortest; 3rd to 10th 1.2–1.6 times as long as 2nd one; scape 1.2–1.3 times thicker than other antennomeres; ratio of antennomeres in one male = 19: 14: 21.5: 21.5: 21: 19: 18: 18: 17.5: 17: 22.5, in one female = 17: 14: 22: 21: 20: 19: 18: 17: 17.5: 17: 20.5. Mandibles relatively short, slender, with pointed apices. Labrum weakly transverse, with six setae along a straight anterior margin. Clypeus slightly transverse, hexagonal, with two lateral setae in anterior third. Tooth of mentum rather large, wide, narrowly rounded at apex, with two basal setae. Submentum on each side with one long and one short seta at posterior margin, and with one long seta at anterior angle. Gula smooth. Temples short, about 1/3 diameter of eye, smoothly merging into a wide neck. Two supraorbital setae in the middle and at posterior margin of eye. Frontal grooves deep and wide, slightly projecting beyond anterior supraorbital setae; weakly converging anteriorly from setae to clypeus, sharply diverging on clypeus to its lateral margins; grooves and area behind apex of frontal grooves with scattered, but rather coarse punctures.

Pronotum (Figs 5, 6) cordate, regularly and moderately convex, slightly transverse (PW/PLm = 1.21–1.35, M 1.26), wider than head (PW/HW = 1.23–1.34, M 1.30), with maximum width at 3/5 off base. Anterior margin straight, distinctly bordered from anterior angles towards 2/3 to midline. Anterior angles not projecting forward, with shortly pointed apices. Lateral sides rather strongly and uniformly convex, long and rectilinear before posterior angles. Lateral margins narrow throughout; with two lateral setae on each side:



Figs 1–4. *Bembidion sanatum*, dorsal habitus: 1, 2 – *B. sanatum iwanai*, ssp. n.: 1 – male, 2 – female ; 3, 4 – *B. sanatum sanatum*: 3 – male, 4 – female.

before maximum width and at posterior angles. Base slightly and uniformly convex throughout, slightly wider than anterior margin (PB/PA = 1.04–1.11, M 1.08). Posterior angles distinct, rectangular, pointed at apices. Midline thin, distinct from anterior margin to a basal transverse bulge. Anterior transverse impression very weak or absent, often distinctly punctate in middle part. Basal fovea large, rounded, deep; their basal half and area between them rather coarsely punctured.



Figs 5–16. *Bembidion sanatum*, details: 5, 6, 9, 10, 13, 14 – *B. sanatum iwanai*, ssp. n.; 7, 8, 11, 12, 15, 16 – *B. sanatum sanatum*; 5–8 – pronotum; 9–12 – elytral striation; 13–16 – microsculpture of elytra near series umbilicata; 5, 7, 9, 11, 13, 15 – males; 6, 8, 10, 12, 14, 16 – females.

Elytra (Figs 1, 2, 9, 10) oval, wide (EL/EW = 1.45–1.62, M 1.53; EW/PW = 1.56–1.73, M 1.66), long (EL/PLt = 2.87–3.18, M 2.98), rather strongly convex, with maximum width near 2/3 basal part. Shoulders prominent regularly rounded. Basal border reaching the apex of 5th groove, smoothly passing into lateral margin. Lateral sides in anterior half slightly convex, in posterior half regularly and arcuately narrowed towards apices; preapical sinuation absent. Apical angle rounded, forming a short gap between elytra. 1st–6th grooves small, superficial at apex, finely punctured throughout; 7th groove smoothed, outlined only by punctures in basal half, at apex with one apical and one preapical pore. Parascutellar stria rather long finely punctured, parallel to suture. Elytral intervals flat throughout or 1st–5th barely convex in basal half. Scutellar pore rather large, joining with 1st and 2nd striae at base; 3rd interval with two small discal pores placed near 3rd stria at 1/3 or 2/3 off base, respectively. Series umbilicata consisting of eight setae: four in humeral group, two at 2/3 off base, and two near apex. Hind wings well-developed.

Ventral surface smooth, impunctate. Metasternal process pointed at apex, sharply bordered. Metepisterna long, along outer margin approximately twice as long as wide along anterior margin (measured in two males and one female). Abdominal sternites simple, each with one pair of setae, with neither additional hairs nor setae. Anal sternite in males with microsculpture of fine transverse lines, with two apical setae; in females with microsculpture of barely noticeable, strongly transverse cells, with four apical setae.

Legs long, slender; hind tarsus 0.79–0.89 times as long as hind tibia; ratio of metatarsomeres 1–5 as 14: 6: 6: 4: 13; in males, the 1st protarsomere strongly enlarged, and the 2nd moderately enlarged.

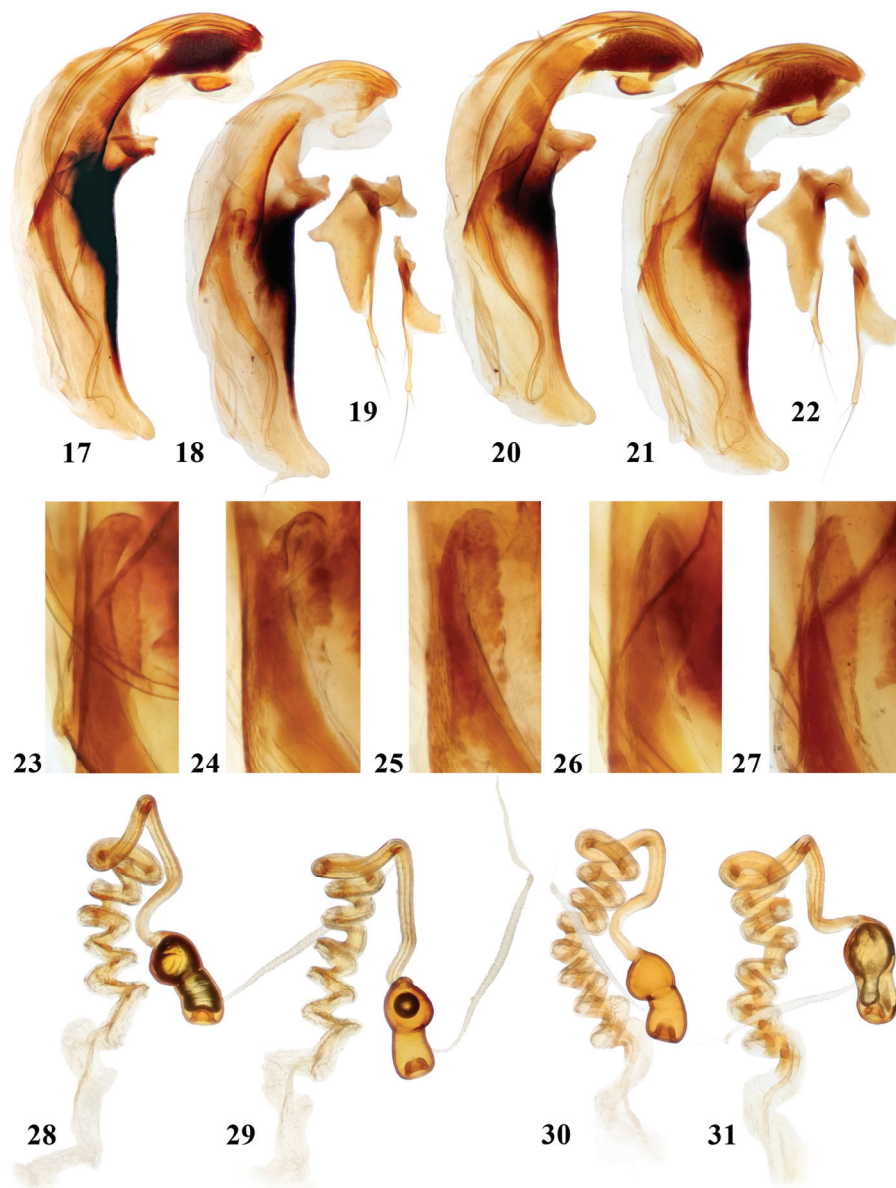
Male genitalia. Aedeagus (Figs 17, 18) large, about half as long as elytra (AL/EL = 0.53–0.55), with prominent basal sclerites. Lamella short, with a rounded apex; ventral surface of aedeagus without projection. Ribbon brush large, entirely protruding from basal part of aedeagus. Basal chitin platelet well-developed, extended anteriorly; ventral chitin platelet barely visible. Main sclerite long, its distal part a long flagellum running side by side with spur of lamina 1 (lama paracopulatrice); base of lamina 1 rounded (Figs 23–25). Left paramere (Fig. 19) wide, triangular, with a small, trapezoidal, outer lobe; right paramere narrow, with a large outer blade; their chaetotaxy variable: left paramere with two (rarely a single) apical and two subapical setae, right paramere with three (rarely two) apical and one or two subapical setae.

Female genitalia (Figs 28, 29). Spermatheca duct long, well-sclerotized, with five or six revolutions. Spermatheca with two chambers subequal in length; basal chamber noticeably asymmetric, convex on one side with gland opening at apex, apical chamber slightly curved.

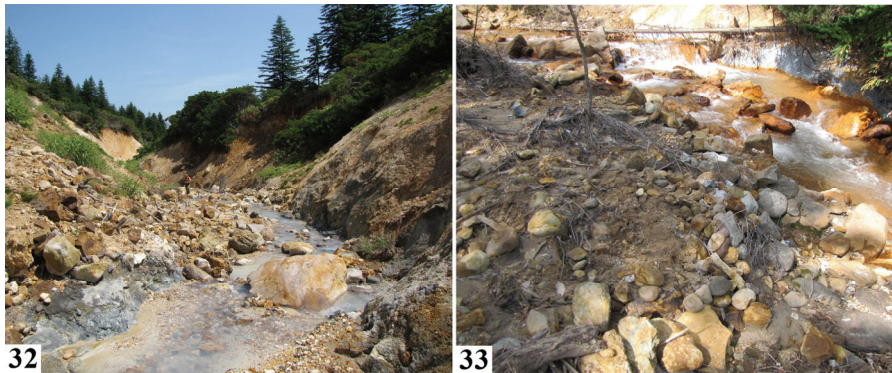
DIAGNOSIS. By the size, colouration, and proportions, *B. sanatum iwanai* ssp. n. is similar to the nominative subspecies, but the pronotum is slightly larger (PLm/EL 0.32, vs. 0.31; PW/EW 0.61, vs. 0.69). The microsculpture of the outer elytral intervals is less strongly developed than in the nominative subspecies, while the 7th and 8th elytral intervals in the new subspecies are usually narrower than 6th (0.9–1.1, vs. 1.0–1.2 in the nominative subspecies). The lamella of the aedeagus is somewhat narrower; the basal part of lamina 1 is rounded (vs. angular in the nominative subspecies). The spermatheca duct shows a lower number of convolutions (5–6, vs. 7–8 in the nominative subspecies).

DISTRIBUTION AND HABITAT. Known only from the type locality, i.e. the valley of Kislaya that stems from the northeastern solfatara field of the Mendeleyev Volcano. Beetles are encountered under riverside stones in the middle flow part of the river where water temperatures are already lower, but both mineralization and acidity remain considerable (Figs 32, 33).

ETYMOLOGY. The type series of the new subspecies was collected in the valley of Kislaya River where sulfur had previously been mined. Thus, the epithet comes from the Ainu “*iwanai*”, meaning “a valley with sulphur” (Batchelor, 1905: 42).



Figs 17–31. Male and female genitals of *Bembidion sanatum*: 17–19, 23–25, 28–29 – *B. sanatum iwanai*, ssp. n.; 20–22, 26–27, 30–31 – *B. sanatum sanatum*; 17, 18, 20, 21 – aedeagus; 19, 22 – parameres; 23–27 – basal part of lamina 1; 28–31 – spermatheca.



Figs 32–33. Habitat of *Bembidion sanatum iwanai*, ssp. n.: 32 – upstream of Kislaya River; 33 – the bank of Kislaya River in the middle reaches.

DISCUSSION

The location of the Mendeleev Volcano at the sea coast and its developed network of solfatara fields determine the high diversity and mosaic of environmental conditions on the volcano's slopes. To a large extent because of this, the flora of the volcano is fairly rich, an almost third of the vascular plant species being encountered there (Sabirov *et al.*, 2014), of a total of 1,078 species known from Kunashir (Barkalov, 2009). There are rather rare species among them, but neither endemics nor relicts.

An evaluation of the faunistic diversity of the Mendeleev Volcano is still impossible, but at least two endemics, *C. elisae kunashirensis* and *B. sanatum iwanai* ssp. n., are known. It seems noteworthy that evaluating the degree of endemism of the Kunashir fauna is hampered by the insufficient knowledge not so much of the island's fauna than by those of the adjacent faunas. A number of Coleoptera taxa originally described from Kunashir and formally treated as its endemics have since been found in other regions or synonymized with widespread species. In this context the family Lycidae may serve as a vivid example. Kryvolutskaja (1973) delimited a "Kuril subgroup" of eight species in that family, for which the status of endemics was suggested, albeit with due reservations. Further studies (Kazantsev, 1993, 2011) have resulted in that the list of presumed endemics has been reduced to two. Similar cases concerned a new histereid species, *Margarinotus kurbatovi* (Tishechkin, 1992), described from Kunashir, but later recorded also from Hokkaido, Honshu and Shikoku (Ohara, 1993), as well as a whole number of Pselaphidae beetles. This is a well predictable result since over most of the Pleistocene and early Holocene both Kunashir and Hokkaido formed a single land (Alekseev, 1978; Igarashi & Zharov, 2011; Minato & Ijiri, 1976; Pietsch *et al.*, 2003; Velizhanin, 1970), whereas most of the presumed endemics are capable of active dispersal.

The above, however, does not concern the two carabid subspecies mentioned before. Both are capable of flight, but both are restricted to solfatara field areas. In addition both subspecies are characterized by clear-cut hiatuses. *Cylindera elisae kunashirensis* has been shown to demonstrate genetic distinctions that exceed multifold the genetic differences from the other intraspecific forms of *C. elisae* (Makarov *et al.*, 2020). Likewise, the new subspecies of *B. sanatum* described above, along with the minimum peripheral differences from the nominative subspecies, shows stable structural peculiarities of the genital apparatus, both male and female, which level is close to those between the species of the subgenus *Peryphanes* Jeannel, 1941.

It is obvious that the causes for and ways of the formation of endemic forms can be different. The well-studied terrestrial mammals of Japan (Millien-Parra & Jaeger, 1999) have been shown to have developed their modern fauna as the result of extinction events that has not been compensated for by new colonist species. Similar trends have been noted for the small mammals of Kunashir (Oshida *et al.*, 2016). A successive impoverishment of the carabid fauna of the Kuril Chain has been demonstrated by Kholin (1993). Therefore, we can a priori suggest that the carabid taxa endemic to the Mendeleev Volcano could have evolved as the result of the ancestral forms extinctions from a considerable area. What still remains in dispute are the pathways their ancestral forms penetrated to Kunashir and the timing of their isolation.

Even though the Mendeleev Volcano seems to have emerged in the mid-Pleistocene as an underwater central block of the Kunashir Island, it remains subaerial during the last 500 thousand years, preserving its land connection to Hokkaido at least between the Middle Pleistocene to early Holocene (Pushkar *et al.*, 1998; Razjigaeva *et al.*, 2002, 2009). The formation of the subaerial part of the volcano was followed by catastrophic caldera-forming eruptions that could have led to the destruction of most of the volcano's cone in the Pleistocene (Middle Würm) and Holocene, 36 and 2.5 thousand years ago (Abdurakhmanov *et al.*, 2004). In addition, as those eruptions of the Mendeleev Volcano could have taken place in the early episodes of considerable climate cooling (Sakagushi, 1983; Yasuda, 1995; Razjigaeva *et al.*, 2014), this combined seems to have hardly allowed *B. sanatum* survival on the Mendeleev Volcano. Therefore, the nearly simultaneous and the strongest mid-Würm eruptions of both Mendeleev and Golovnin volcanoes that completely destroyed the natural territorial complex of the southern Kunashir Island (Melekestsev *et al.*, 1974, 1988; Razjigaeva *et al.*, 2014) could soundly be taken as the lowest temporal limit whence a successful colonization of the Mendeleev Volcano could be suggested following a strong eruption (ca. 2.5 thousand years ago).

The modern looks of the Mendeleev Volcano appeared later. The formation of the volcano's considerable cone was completed following a strong eruption ca 2.5 thousand years ago, while pyroclastic flows formed at that time an adjacent coating (Abdurakhmanov *et al.*, 2004). It was the development of a cone that seems to have provided the maintenance of the *B. sanatum* population on the Mendeleev Volcano. To confirm this, the nearest Golovnin Volcano can be taken as an example. Its evolution stopped at the stage of a caldera which originated simultaneously with (Melekestsev *et al.*, 1974) or slightly later than the caldera of the Mendeleev Volcano (Bazarova *et al.*, 1998), but it has no endemics of its own at the present time.

However, this fails to account for the current distribution of *B. sanatum iwanai* ssp. n. which, like *Cylindera elisae kunashirensis*, is restricted to the solfatara fields of the Mendeleev Volcano. These environments are even geologically younger and they seem to have evolved simultaneously along the circular cracks at the peripheries to the volcano's extrusive cupola (Lebedev *et al.*, 1980; Abdurakhmanov *et al.*, 2004). Such a narrow localization looks unusual, because *B. sanatum* beetles are winged, whereas the nearest solfatara fields are situated some 20–25 km away from the type locality. As it has been demonstrated elsewhere, the remaining winged carabid species inhabiting solfatara fields are widespread across the island (Makarov *et al.*, 2020). Such distributions of both *B. sanatum iwanai* ssp. n. and *C. elisae kunashirensis* seem too hard to explain by a hypothesized life in some environmental conditions other than highly particular. This idea does deserve consideration, since the waters of Kislaya River in its upper course are considerably enriched with Fe^{2+} (3–7 times more than on the other volcanoes and almost by one order of magnitude more than in ground waters), whereas the content of the other cations and anions is often considerably lower (Zharkov, 2014). *B. sanatum iwanai* ssp. n. seems to have become isolated during the maximum

glaciation times and passed through the stage of sparse populations in the zones of the volcano's thermal activities. The isolation could have increased with sea transgressions which are known to have reached the maximum in the Atlantic phase of the Holocene, ca 3.7 thousand years ago, when the Sernovodsk Isthmus is known to have been a sea strait (Korotky *et al.*, 1998).

To summarize, the fauna of Kunashir represents a remarkable example of endemism on a relatively small island. At the moment, each of the island's large volcanic massifs supports endemic insect taxa: in the north, the Ruruy and Tyatya volcanos are the habitat of ground beetle *Bembidion ruruy* Makarov et Sundukov, 2014 (Carabidae), the cave cricket *Alpinanoplophilus kurilensis* Storozhenko, 2015 (Rhaphidophoridae), and a genetically highly divergent populations of *Podisma* cf. *sapporensis* Shiraki, 1910 (Acrididae), whereas the Mendeleev Volcano has two clearly distinguished carabid subspecies. This situation deserves attention and is worth of further research.

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