

Taxonomic Notes on *Rhizocarpon* Growing in Solfataras Fields in Japan

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Abstract Five species of *Rhizocarpon* growing in a solfataric field are reported for Japan. *R. vulcani* Mas. Inoue is new to science. *R. oederi* (Weber) Körber is new to the flora of Asia. Taxonomic and chemical data are provided.

Key words : lichens, taxonomy, *Rhizocarpon*, active volcanic area, solfataras, Japan

The Japanese archipelago has numerous volcanoes. It is known that the vegetation near solfataras in the volcanic areas are severely affected by sulphurous gases including H₂S, SO₂ and others, and that characteristic communities such as *Cladonia vulcani*–*Descampsia flexuosa*-community and *Caricetum angustisquamae*-community are developed. There exist some ecological studies on lichens in this harsh habitat of Japan (Glime and Iwatsuki, 1990; Fahselt, 1995; Inoue, 1996; etc.), but most crustose lichens growing there are still unknown. In this paper I will present some notes on five species of Japanese *Rhizocarpon* growing near solfataras; *R. atrobrunnescens*, *R. badioatrum*, *R. lavatum*, *R. oederi* and *R. vulcani*.

Nylander (1890) added *Rhizocarpon atrobrunnescens*, *R. badioatrum* (as *Lecidea atroalba*) and *R. lavatum* to the lichen flora of Japan based on the collections from Mt. Fuji, and the mountain was the only locality of these lichens previously known and their existence in Japan were not reconfirmed except for *R. badioatrum* by Fahselt (1995). The type and authentic specimens of possibly related species from extra-Japan have been restudied for purposes of comparison.

In the list of specimens examined, the locality is followed by the altitude, accession number and the date collected. The specimens listed here are preserved in the herbarium of Akita University and in the herbarium of the National Science Museum, Tokyo (TNS).

1) *Rhizocarpon atrobrunnescens* (Nyl.) Zahlbr. (Plate I: a)

Cat. Lich. Univ. 4: 347 (1926).—*Lecidea atrobrunnescens* Nyl., Lich. Jap. p. 82 (1890). Type: Japan, Mt. Fuji “in limite arborum”,—holotype in H (H-Nyl. 9893), vidi.

Thallus dark brown, polished, peltate or subsquamulose-areolate; areolae sub-

scattered, with epinecral layer, more or less round, concave with blackish margin. Hypothallus black, visible between the areolae.

Apothecia reaching a diameter of 0.5 mm, black, appressed-adnate or subimmersed in the thallus; disc epruinose, plane or convex, with somewhat thick margin; margin almost level with the disc surface. Excipulum thin, 30–50 μm thick, dark brown, paraplectenchymatous; hyphae obliquely subradiating, with a thin wall. Epithecium blackish green. Hymenium 120–150 μm high. Subhymenium colorless, 15–20 μm high. Hypothecium dark brown, reaching to 150 μm high. Paraphyses branched, anastomosed. Asci clavate, 100–130 \times 35–45 μm , 8-spored. Spores (30–)32–40(–42) \times 16–18(–20) μm , muriform, with 5–7 transverse septa and 1–2 longitudinal septa, colorless at first, soon becoming brown, with halo.

Reactions: thallus & medulla P-, K-, KC-, C-. Chemical substances: two unidentified minor constituents (Fig. 1). Habitat: on rocks. Range: endemic to Japan.

Rhizocarpon atrobrunnescens is closely related to *Rhizocarpon bolanderi* (Tuck.) Herre, known from northern North America, Greenland and Scandinavia, because of having peltate or squamulose areolae which are dark brown and polished, and of having numerous-celled muriform spores. However, *R. bolanderi* has asci producing 1 or 2 bigger spores (32–68 \times 18–32 μm , Thomson 1997) per ascus.

Rhizocarpon atrobrunnescens is also known to occur in the areas where solfataras are absent.

(Solfataras are present in the locality) Specimens examined: HOKKAIDO. Prov. Kamikawa: Anseikako “Ansei Crater” of Mt. Furano, 1400 m alt., M. Inoue no. 7960b (23 Aug., 1974). HONSHU. Pref. Nagano: Mt. Asama, 2400 m, M. Inoue no. 11342 (23 Aug., 1976), 2130 m, M. Inoue no. 11349 (23 Aug., 1976). (Solfataras are absent from the locality) Representative specimens examined: HOKKAIDO. Prov. Kushiro: Mt. Oakan, 1350 m, M. Inoue no. 8781 (26 July, 1974). Prov. Kamikawa: Mt. Midori of Mts. Daisetsu, 1840 m, M. Inoue no. 11664 (8 Aug., 1974).

2) *Rhizocarpon badioatrum* (Flörke ex Spreng.) Th. Fries (Plate I: b)

Lich. Scand. 613 (1874).—*Lecidea badioatra* Flörke ex Spreng., Neue Entdeck. 2: 95 (1821). Type: Europe?, non vidi.—*Lecidea atroalba* Ach.; Nylander, Lich. Jap. 82 (1890).—*Rhizocarpon badioatrum* var. *atroalbum*; Zahlbr., Cat. Lich. Univ. 4: 326 (1927); Sato, Cat. Lich. Jap. (ed. 2) 47 (1965).

Thallus brown or pale brown, irregularly areolate; areolae plane or slightly bullate, dispersed on a black hypothallus, or in part, contiguous. Hypothallus prominent, black, visible between the areolae.

Apothecia black, reaching a diameter of 1.0 mm, between or partly on the areolae, appressed-adnate, somewhat thickly marginate; margin almost level with the disc surface; disc epruinose, plane or convex. Excipulum thin, 30–50 μm thick, dark brown with violet tinge, paraplectenchymatous; hyphae obliquely subradiating, with a thin wall. Epithecium brown or pale brown, K+ violet. Hymenium 100–120 μm

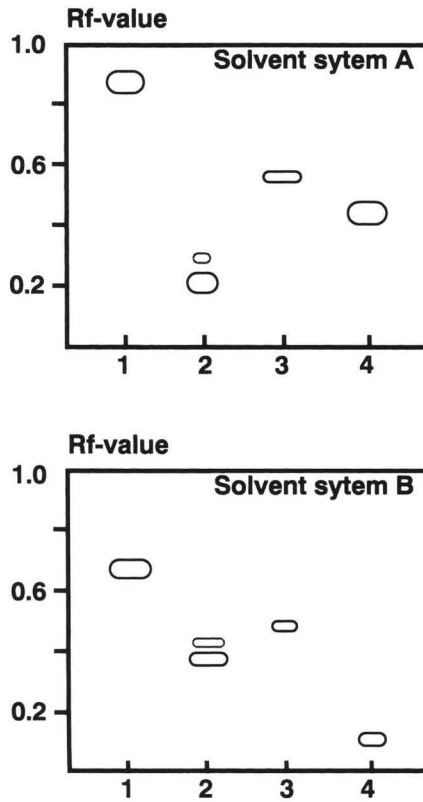


Fig. 1. Chromatograms of *Rhizocarpon atrobrunnescens* in solvent systems A and B comparing with norstictic acid, etc. 1. atranorin; 2. *Rhizocarpon atrobrunnescens*; 3. norstictic acid; 4. stictic acid. (solvent system A: a mixture of 180 ml of benzene, 45 ml of dioxane, and 5 ml of acetic acid; solvent system B: a mixture of 100 ml of *n*-hexane, 80 ml of ethyl ether, and 20 ml of formic acid.)

high. Subhymenium 15–20 μm high, pale brown or colorless. Hypothecium concolorous to the excipulum, reaching to 150 μm high. Paraphyses branched, anastomosed. Asci clavate, 80–100 \times 20–35 μm , 8-spored. Spores colorless at first, soon becoming brown, 1-septate, with halo, 20–23 \times 11–13 μm .

Reaction: thallus & medulla P-, K-, KC-, C-. Chemical substances: two unidentified minor constituents (same as those of *R. atrobrunnescens*, Fig. 1). Habitat: on rocks. Range: Japan; Italy (Nimis & Poelt, 1987); Germany (Feuerer, 1978); Sweden (Malme, 1914); Svalbard Isls. (Elvebakk & Hertel, 1997); Greenland (Lyngge, 1934; Thomson, 1997); American arctic (Thomson, 1997); Australia (Filson, 1996); India (Schubert & Klement, 1966)

Rhizocarpon badioatrum is most reminiscent of *Rhizocarpon hochstetteri* (Körb.) Vainio, known from northern Hemisphere including Japan (Inoue, 1997),

which resembles in having similar thallus and spore morphology. However, *R. hochstetteri* has spores which are always colorless except for those of very old stage and producing stictic acid.

Kümmerling (1991) reported stictic acid from *R. badioatrum*, and Follmann & Huneck (1971) reported an unidentified phenolic substance. On the contrary Japanese representatives show different chemistry. There might be existing some chemotypes in *R. badioatrum*.

Nylander (1890) reported *Lecidea atroalba* "Ach." from Japan (Fuji-Ichigome, on lava), which Sato (1965) mentioned as a synonym of *Rhizocarpon badioatrum* var. *atroalbum* "(L.) Malme" when he summarized the Japanese lichens known up to 1958 with no attempt at taxonomic revision and was based chiefly on Zahlbruckner's Catalogus, but unfortunately I could not find out any voucher specimen from Nylander Herbarium at Helsinki University both on 1977 and 1994.

Rhizocarpon badioatrum is also known to occur in the areas where solfataras are absent.

(Solfataras are present in the locality) Specimens examined: HOKKAIDO. Prov. Kamikawa: Ansei Kako (Ansei-Crater) of Mt. Furano, 1400 m, M. Inoue no. 7960 a (23 Aug., 1974). Prov. Nemuro: Kamuiwakka of Shiretoko Pen., 740 m, coll. D. Fahaselt (H43), M. Inoue no. 23558 (17 Oct., 1989); Mt. Kawayu-iouzan, 150 m, M. Inoue no. 9039 (15 Aug., 1974). Prov. Kushiro: Mt. Meakan, 1250 m, coll. D. Fahaselt (H38), M. Inoue no. 23561 (14 Oct., 1989); 1255 m, coll. D. Fahaselt (H39), M. Inoue no. 23562 (14 Oct., 1989); 1260 m, coll. D. Fahaselt (H29, 37), M. Inoue nos. 23559, 23560 (14 Oct., 1989). Prov. Shiribeshi: Niseko Heights, 900–1000 m, M. Inoue no. 24679 (16 July, 1984). HONSHU. Pref. Gunma: Mt. Motoshirane, 2000–2140 m, M. Inoue no. 24462 (3 June, 1984). (Solfataras are absent from the locality) Representative specimens examined: HOKKAIDO. Prov. Abashiri: Mt. Rausu of Shiretoko Pen., 1650 m, M. Inoue no. 7750 (23 July, 1974). Prov. Kushiro: Mt. Oakan, 1350 m, M. Inoue no. 8755 (26 July, 1974). Prov. Tokachi: Mt. Yuniishikari–Mt. Otofuke, 1640 m, M. Inoue no. 8377 (4 Aug., 1974). HONSHU. Pref. Yamaguchi: Mt. Kitadake, 3050 m, M. Inoue no. 12193 (19 Aug., 1978). Additional specimens examined: SWEDEN, Västmanland, Arboga, Sfielund, on a boulder, coll. G. Kjellmert, s.n. (25 March, 1953), TNS. AUSTRIA, Östzaler Alpen, Nord tirol, Kaunergrat, 2220–2230 m, coll. H. Doppelbauer & A. Schröppel (Aug., 1961), Lich. Alpium no. 169, TNS.

3) *Rhizocarpon lavatum* (Fr.) Hazslin

(Plate I: c)

Magy. Birod. Zuzumo-Flor., 206 (1884). — *Lecidea atroalba* var. *lavata* Fries, Nov. Sched. Critic. p. 18 (1827). Type: Sweden, Smaland, Femsjö, coll. E. Fries, non vidi. — *Lecidea lavata* Ach.; Nyl. Lich. Jap. p. 82 (1890).

Thallus thin to medium, ochraceous or in part brownish gray, irregularly cracked-areolate; areolae minute, contiguous, or in part more or less dispersed, sur-

face mat. Hypothallus indistinct or forming a black hypothalline line.

Apothecia up to 0.7 mm wide, black, adnate, well constricted at the base; disc epruinose, flat with a prominent entire margin at the juvenile stage, then becoming slightly convex with +/- obliterated margin, with umbo. Excipulum up to 70 μm thick, dark brown, paraplectenchymatous; hyphae perpendicularly radiating 5–7 μm thick, with a thin wall. Epithecium brown. Hymenium (110)120–140(150) μm high. Subhymenium 15–20 μm high, pale brown. Hypothecium reaching to 150(–200) μm high, dark brown. Paraphyses slender, 2–3 μm thick, well branched, anastomosed; apices not swollen. Asci clavate, 105–130 \times 25–30 μm , 8-spored. Spores 23–33 \times 12–20 μm , with halo, colorless, muriform, with 4–6 transverse septa and 1–2 longitudinal septa.

Chemical reactions: thallus & medulla P-, K-, KC-, C-; Chemical substances: no lichen substances demonstrated on TLC. Habitat: on rocks close to running water and are temporary inundated. Range: Japan; Europe (Feuerer, 1991; Purvis *et al.*, 1992; Santesson, 1993); North America (Wong & Brodo, 1992); Svalbard Isls. (Elvebakk & Hertel, 1997)

Rhizocarpon lavatum is distinctive by the ochraceous or brownish gray thallus, adnate apothecia with umbonate disc, the colorless muriform spores and by the peculiar habitat. This species is known in Japan only from three present gatherings, but the materials are well developed, and actually this species is forming large communities at the site.

This species is most reminiscent of *Rhizocarpon oederi*, since these two species have a similar thallus, apothecia and a chemistry. However, *R. oederi* has a lower hymenium (up to 100 μm high) and smaller parallel 3-septated spores (18–20 \times 8–10 μm).

Rhizocarpon lavatum is known as a lake- and stream-side species (Purvis *et al.*, 1992; Wong & Brodo, 1992, *etc.*). The Japanese representatives are also occurring in the similar habitat where are temporary inundated (Plate II: b). But Sukawa, where is the only known locality of this species at present, is situated on a volcanic area where abundant active solfatars are formed among or on lavas, and the running water near the habitat is acidic and contains extremely high level heavy metals on the contrary to a mention of Purvis *et al.* (1992) “on siliceous rocks subject to inundation by unpoluted streams and lakes”. I measured the pH values and the electroconductivity, which is one of the parameters of salinity, of the stream water close to the habitat at Sukawa; pH value is 2.72–2.78 and the electroconductivity is 1108–1114 $\mu\text{S/cm}$.

Nylander (1890) reported this species (as *Lecidea lavata*) from Japan (Mt. Fuji, Oumagayeshi – Itchigome), but unfortunately I could not find out the voucher specimen from the Nylander Herbarium at Helsinki University on both 1977 and 1994.

Specimens examined. HONSHU. Pref. Akita: Sukawa, on the mountain side of Mt. Kurikoma, 1080–1100 m, M. Inoue nos. 25773 & 25774 (15 Sept., 1997), 27632 (18 June, 2000). An additional specimen examined. Sweden, Bohuslä: Skaftö, Klu-

bban, coll. A. H. Magnusson, s.n. (16 July, 1922), TNS.

4) *Rhizocarpon oederi* (Weber) Körber (Plate I: d)

Parerga Lich., p. 232 (1861). — *Lichen oederi* Web., Spicil. Flor. Goettingens., p. 182 (1778). Type: Germany, Harz, non vidi.

Thallus contiguous, thin to medium, ochraceous, irregularly cracked-areolate, surrounded by brownish hypothalline lines; areolae angular, flat, smooth, more or less polished.

Apothecia up to 0.5 mm wide, black, subimmersed to appressed-adnate on the thallus or among the areolae, not constricted at the base; margin prominent; disc epruinose, with umbo. Excipulum up to 60 μm thick, paraplectenchymatous, dark brown. Epithecium blackish green or paler. Hymenium (60)70–90 μm high. Subhymenium 15–20 μm high, pale brown. Hypothecium reaching to 100(150) μm high, dark brown. Paraphyses slender, 2–2.5 μm thick, well branched, anastomosed. Asci clavate, 50–60 \times 15–20 μm , 8-spored. Spores colorless, oblong, with halo, 3-septated, 16–21 \times 7–10 μm .

Reaction: thallus & medulla P-, K-, KC-, C-. Chemical substances: no lichen substances demonstrated on TLC. Habitat: on rocks. Range: Japan; Svalbard (Elvebakk & Hertel, 1997); North & Central Europe (Feuerer, 1978 & 1991; Santesson, 1993; Schade, 1935); North America (Thomson, 1967; Wong & Brodo, 1992).

Diagnostic characteristics for this species are: the ochraceous thallus which is surrounded by brownish hypothalline lines, the subimmersed to appressed-adnate apothecia with umbo, and the colorless 3-septated spores.

Yamada Pass, where is one of the known localities of this species, is not situated on the site close to the solfataras but on the site about 1.3 km northwest of the crater of Mt. Shirane, where numerous solfataras are formed, being affected by sulphurous gasses.

This species was previously known only from Arctic region, Europe and North America. However, the range has now extended to Asia.

(Solfataras are present near the sites) Specimens examined. HONSHU. Pref. Nagano: Yamada Pass in Mt. Shirane, 2060 m, M. Inoue nos. 1764 b & 11890 (20 July, 1972), 2100 m, M. Inoue nos. 24745b, 24746 & 24750 (2 June, 1984). (Solfataras are absent from the site) Specimens examined. HOKKAIDO. Prov. Tokachi: Mt. Ishikari, 1860 m, M. Inoue no. 8470 (5 Aug., 1974). Additional specimens examined. Slovakia, Carpathes, 500 m alt. coll. Kiszely & Vězda (30 Aug., 1974), Vězda, Lich. sel. Exs. no. 1295, TNS. Finland, “Tavastia meridionali, Ronni”, coll. C. Leopold (in 1876), Norrlin & Nylander’s Exs. no. 343, TNS.

5) *Rhizocarpon vulcani* Mas. Inoue, sp. nov. (Plate II: a)

Thallus crustaceus, epilithicus, modice incrassatus aut sat tenuis, atrofuscescens, irregulariter areolatus aut verrucoso-areolatus; areolae minutae, leviter convexae, dis-

persae aut discretas. Hypothallus nigricans. Apothecia ad 0.5 mm lata, tota adnata, ad basin leviter constricta, disco vulgo plano, saepius umbonata, nigra, nudo, margine prominente, persistente. Excipulum 30–50 μm latis, fusco-grauescens. Epithecium aeruginoso-fuliginosum. Hymenium (90–)100–120 μm crassum. Subhymenium 15–20 μm crassum, decoloratum aut pallidum. Hypothecium totum fusco-nigrum, ad 100 μm crassum. Paraphyses graciles, passim ramoso-connexae. Asci clavati. Sporae 8-nae, ellipsoideae, decolores, murales, 22–26 μm longae, 11–15 μm crassae.

Thallus dark brown, thickness medium, irregularly areolate or verrucose-areolate; areolae minute, surface mat, plane or slightly convex, or at times granulated, more or less dispersed on a black hypothallus, or in part, contiguous; medulla I-. Hypothallus black, visible between the areolae.

Apothecia up to 0.5 mm wide, adnate or appressed-adnate, black, between or partly on the areolae, slightly constricted at the base; disc epruinose, plane, at times with umbo; margin prominent, thick. Excipulum thin, 30–50 μm thick, dark brown with green tinge, paraplectenchymatous; hyphae obliquely subradiating, with a thin wall. Epithecium blackish green. Hymenium (90–)100–120 μm high. Subhymenium 15–20 μm high, colorless or pale brown. Hypothecium dark brown, reaching to 100 μm high; hyphae irregularly arranged. Paraphyses slender, 1.5–2.5 μm thick, well branched, anastomosed; apices not or slightly thickened. Asci clavate, 80–100 \times 25–35 μm , 8-spored. Spores 22–26 \times 11–15 μm , colorless, ellipsoid, muriform, with 3 (or rarely 4) transverse septa and 1 longitudinal septa, with halo.

Reaction: P-, K-, KC-, C-. Chemical substances: no lichen substances demonstrated on TLC. Type: Japan, Honshu, Pref. Akita, Senpoku-gun, Tazawako-machi, Tamagawa spa, 760 m alt., on rock, 15 Oct., 1983. M. Inoue no. 16569, — holotype in TNS. Habitat: on rocks in volcanic areas where abundant solfataras are spouting acidic gases. Range: Endemic to Japan.

Rhizocarpon vulcani reminds *Rhizocarpon grande* (Flörke ex Flotow) Arnold, which is one of the well known species in northern Hemisphere and New Zealand and is known from the Shirakami Mountains of Japan (Inoue & Moon, 1996), because of having dark brown thallus of which areolae are dispersed on a black hypothallus and of having muriform spores. However, *R. grande* can be easily distinguished by having dark brown bigger spores (30–35 \times 16–18 μm) with 4 to 7 transverse septa and 1 to 2 longitudinal septa, and by containing gyrophoric acid as a major substance.

Spores of most samples of *R. vulcani* including type specimen always colorless, however, a few ones have pale brown spores which are old and changing from normal shape.

Rhizocarpon vulcani is distributed from Hokkaido to Kyshu and is occurring in volcanic areas where solfataras are spouting hot smokes and gases; perhaps it might be one of the common lichens growing in this kind of peculiar habitat like *Cladonia vulcani*. At the Tamagawa spa area Inoue (1996) reported the pH value 3.5 to 4.6

from the water remaining just after a rainfall in small hollows on the rocks, on which *R. vulcani* is growing (Plate II: c).

Specimens examined. HOKKAIDO. Prov. Shiribeshi: Ooyu-numa, Noboribetsu spa, 230 m, M. Inoue no. 24739 (20 July, 1984), Niseko Heights, 900–1000 m, M. Inoue nos. 24683 & 24686 (16 July, 1984). Prov. Iburi: Mt. Nisekoan-nupuri, 1150 m, coll. H. Kashiwadani no. 15588 (20 Sept., 1979), TNS. HONSHU. Pref. Aomori: Shimokita Pen., Mt. Osorezan, lakeshore of Usori-ko, 210 m, M. Inoue no. 25610 (18 Oct., 1996). Pref. Akita: Yugama in Mt. Yakeyama of Hachimantai, 1280 m, M. Inoue no. 25708 (16 May, 1998); Tamagawa spa, 760 m, M. Inoue nos. 23746, 23748, 23750, 23751, 23755–76 (18 July, 1995); Mt. Kurikoma, near Showa-ike, 1300 m, M. Inoue no. 25770 & 25777 (15 Sept., 1997); Mt. Yamabushi, Kawarage-jigoku, 800 m, M. Inoue no. 27628 (5 May, 2000). Pref. Nagano: Mt. Asama, Yunodaira, 2010 m, M. Inoue no. 11325 (23 Aug., 1976); Mt. Ontake, 2630 m, M. Inoue no. 11497 (17 Aug., 1976). KYUSHU. Pref. Nagasaki: Unzen spa in Mt. Unzen, 600 m, M. Inoue no. 2555b (28 March, 1996). Pref. Miyazaki: Ebino Heights (Oojigoku on the foot of Mt. Karakuni), 1350–1400 m, M. Inoue nos. 25493–25495, 25497, 25498, 25506, 25527, 25529, 25539 (27 March, 1996).

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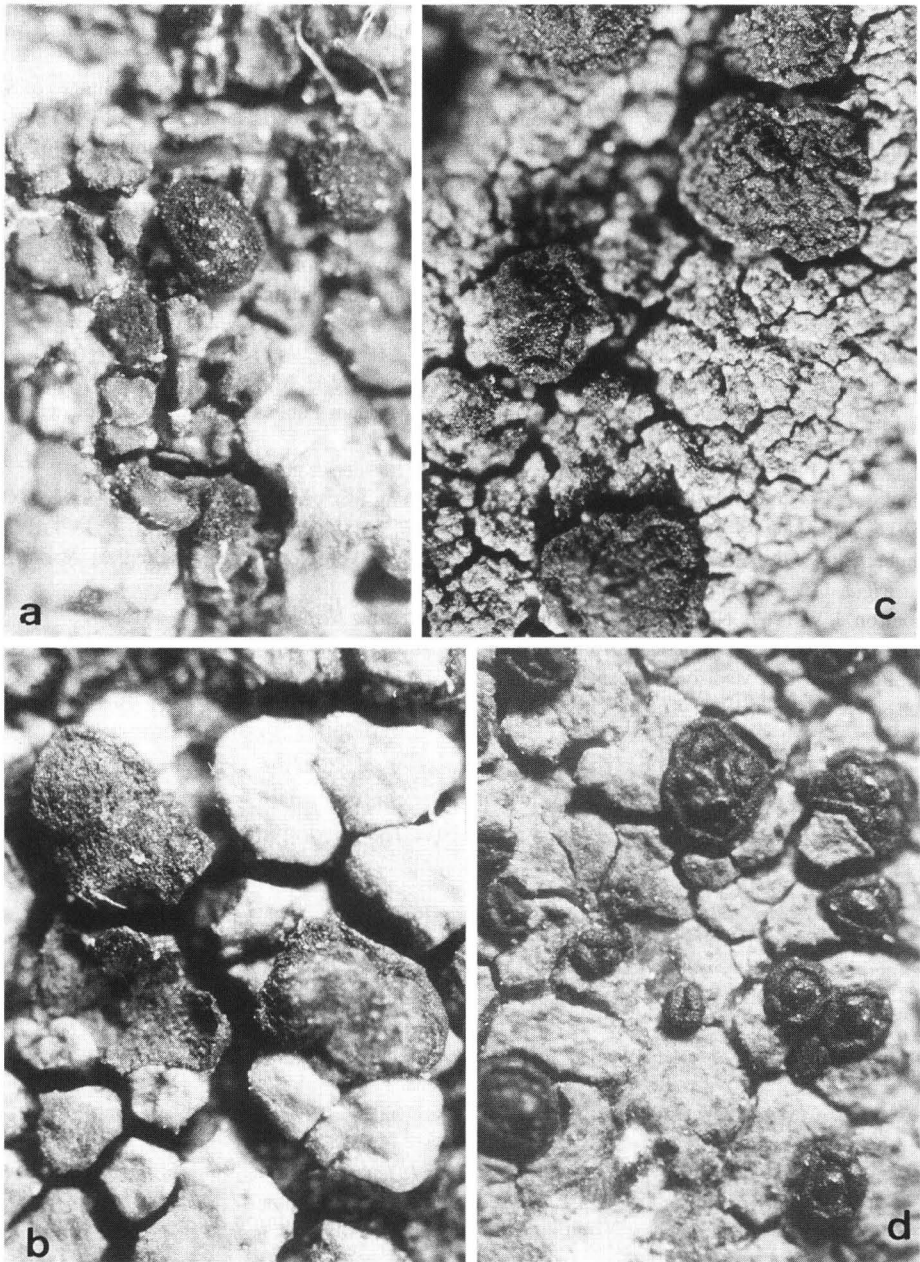


Plate I. a. *Rhizocarpon atrobrunnescens* (Nyl.) Zahlbr. (M. Inoue no. 7960 b). b. *Rhizocarpon badioatrum* (Flörke ex Spreng.) Th. Fries (M. Inoue no. 7960 a). c. *Rhizocarpon lavatum* (Fr.) Hazslin (M. Inoue no. 27632). d. *Rhizocarpon oederi* (Weber) Körber (M. Inoue no. 1764 b).
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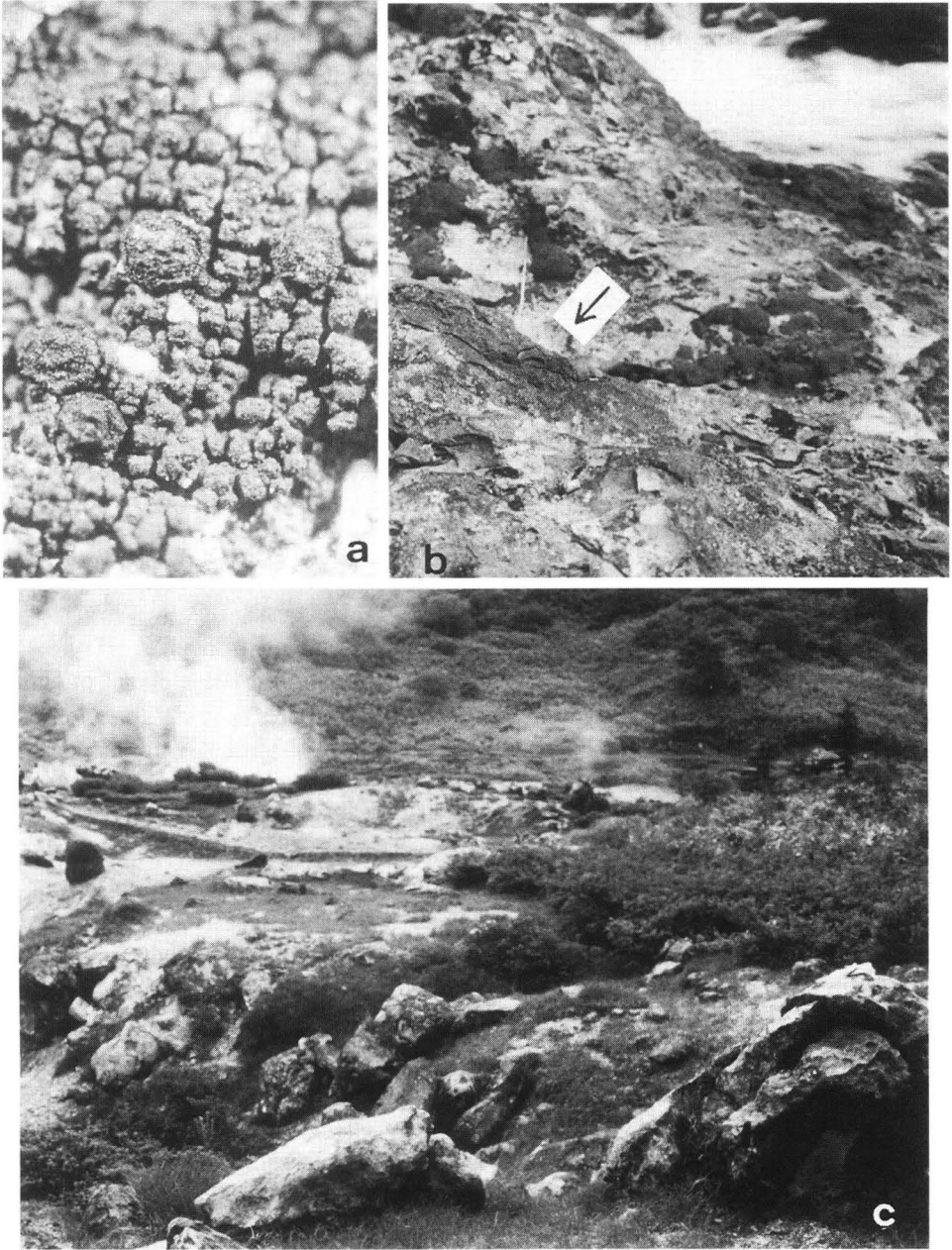


Plate II. a. *Rhizocarpon vulcani* Mas. Inoue (M. Inoue no. 16569, holotype). $\times 10$. b. Habitat of *Rhizocarpon lavatum* (arrow) where is close to running water and is temporary inundated. (Sukawa of Mt. Kurikoma). c. The type locality of *Rhizocarpon vulcani* (Tamagawa-Onsen "spa" where active solfataras are spouting hot smokes and gases).

