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The Diatom Flora of a Steam Vent of Kilauea Crater, Island of Hawaii[1]

MISCHELLE MCMILLAN and SAMUEL R. RUSHFORTH[2]

ABSTRACT: Freshwater and subaerial diatom floras have not been extensively examined in the Hawaiian Islands. This paper reports the study of a subaerial diatom flora in a small steam vent near Kilauea Crater, Island of Hawaii. A total of 35 taxa was identified, 3 of which are new records for the state. The Kilauea vent flora is unusual in floral composition and differs markedly from other Hawaiian subaerial diatom floras we have studied, particularly in the dominance of *Anomoeoneis serians* var. *brachysira* and *Frustulia rhomboides*.

MANY WORKERS in our laboratory have studied the freshwater flora of the Hawaiian Islands for the past several years in an effort to characterize the resident algal taxa. Initially, we examined the flora of several freshwater streams (Fungladda, Kaczmarska, and Rushforth 1983). Subsequently, we studied the subaerial diatom flora of Thurston lava tube (Rushforth, Kaczmarska, and Johansen 1984). The present paper is the first in a series in which the algal floras of unusual subaerial and spring habitats are examined.

This paper discusses the diatom flora of a steam vent of Kilauea Volcano, Island of Hawaii. This vent is located approx. 1 km west of Volcano House near State Highway 11. The vent substrate we collected was a wet wall that was moistened by steam rising from the vent aperture. The steam was cooled by the time it reached the vent opening, condensing and thoroughly moistening the surrounding lava surfaces. Mosses and other bryophytes grew on these walls, as did green and blue-green algae. Diatoms also grew on these walls in association with the bryophytes and algae.

MATERIALS AND METHODS

A composite sample was obtained 28 April 1982 from the surface of the steam vent by scraping algae from exposed lava walls and by collecting visible bryophytes. This material was placed in a vial and returned to our laboratory.

The sample was cleared according to standard methods using boiling nitric acid (St. Clair and Rushforth 1977) and mounted in Naphrax resin. Slides were examined using Zeiss RA microscopes with Nomarski interference-phase and bright-field objectives and accessories. Photographs were taken of each taxon when possible, using Nikon AFM photomicrographic equipment.

In order to obtain information on the diatom community structure, 400 diatom frustules were counted and percent relative density for each taxon was calculated. These data were also used to calculate a Shannon–Weaver diversity index (Patten 1962, Shannon and Weaver 1949).

RESULTS AND DISCUSSION

A total of 15 diatom genera containing 35 taxa was identified in our material. The Kilauea flora was dominated by relatively few species, with the majority being present in low numbers. For instance, *Anomoeoneis serians* var. *brachysira* and *Frustulia rhomboides* together comprised 74.0% of the population. The next two most abundant taxa, *Pinnularia termitina* and *Achnanthes linearis*, contributed 6.7% and 4.4%, respectively, to the population, for a total of 85.1% for the top four taxa.

[1] Manuscript accepted 3 April 1985.
[2] Brigham Young University, Department of Botany and Range Science, Provo, Utah 84602.

Nine of the organisms were present only as single specimens in our count. The dominance of a relatively few taxa in the flora is also reflected by the low Shannon–Weaver diversity index of 1.722.

The Kilauea flora is strikingly different from that of a subaerial wet wall at Thurston lava tube, Island of Hawaii (Rushforth, Kaczmarska, and Johansen 1984), which is only 4 km south of the Kilauea vent. The Thurston flora had a greater biomass of living diatoms and contained 30% more species, for a total of 49 taxa. More important, the Thurston flora had only 7 taxa in common with the Kilauea flora, and the dominant species at the two sites were entirely different. This is interesting since the lava substrates at the two localities were apparently equivalent and the bryophyte floras were macroscopically similar. However, the substrate was wetter at the Thurston site and diatoms not only colonized bryophytes but formed mucilaginous mats directly upon the lava walls as well. This is in contrast to the Kilauea vent site where there was little exposed lava for colonization and the diatoms were primarily epiphytic. In addition, the vent locality was less protected and therefore should experience increased insolation. It is also possible that the steam in the Kilauea vent carries chemicals that influence floral composition.

Many of the organisms we found in the Kilauea vent are cosmopolitan and have been collected on wet walls in other parts of the world. However, the Kilauea flora as a whole is different from any we have studied in North America (Clark and Rushforth, in press; Rushforth et al. 1976) and from those reported in other parts of the world (Hustedt 1930–1966, Patrick 1977). Particularly noteworthy is the absence of *Cymbella* and *Denticula* species and the reduction in *Achnanthes* and *Navicula* species in the Kilauea flora.

Three of our taxa from the Kilauea site represent new records for the Hawaiian Islands. These are *Navicula muticoides*, *Nitzschia frustulum* var. *subsalina*, and *Nitzschia minutula*. In addition, it is likely that our *Gyrosigma* species represents a new record. It is interesting to note that there is an absence of endemic species in the Kilauea vent flora. The apparent paucity of endemic taxa in the Hawaiian flora was discussed by Fungladda, Kaczmarska, and Rushforth (1983) and supports the hypothesis that diatom dispersal to the islands does not seem to be a limiting factor in the development of the local flora and that little local speciation has occurred.

TAXONOMIC SECTION

In the remainder of this paper, each taxon is described and discussed briefly. Taxa are listed alphabetically.

ACHNANTHES

Achnanthes lanceolata (Breb.) Kuetz. (Figure 1, *1*, *2*). Valve 10–12.5 μm long by 5–6 μm wide; striae 14–15 in 10 μm on both valves. Only two valves of this taxon were noted in our material.

Achnanthes linearis (W. Sm.) Grun. (Figure 1, *3*, *4*). Valve 8.5–11.5 μm long by 2–4 μm wide; striae (22)24–26 in 10 μm on both valves. This taxon was fourth most common in our sample, comprising 4.4% of the population. We placed our specimens into *A. linearis* rather than *A. minutissima* on the basis of coarser striation.

Achnanthes montana Krasske (Figures 1, *5*, *6*). Valve 10–12.5 μm long by 5–6 μm wide; striae 18–20 in 10 μm, becoming somewhat finer near ends. This taxon was present at Kilauea only as two valves.

AMPHORA

Amphora normanii Rabh. Valve 26 μm long by 5 μm wide; striae 11–12 in 10 μm. This taxon was present in our collection as a single valve.

ANOMOEONEIS

Anomoeoneis serians var. *brachysira* (Breb. ex Kuetz.) Hustedt (Figure 1, *7*, *8*). Valve 16–21.5 μm long by 5–6 μm wide; striae

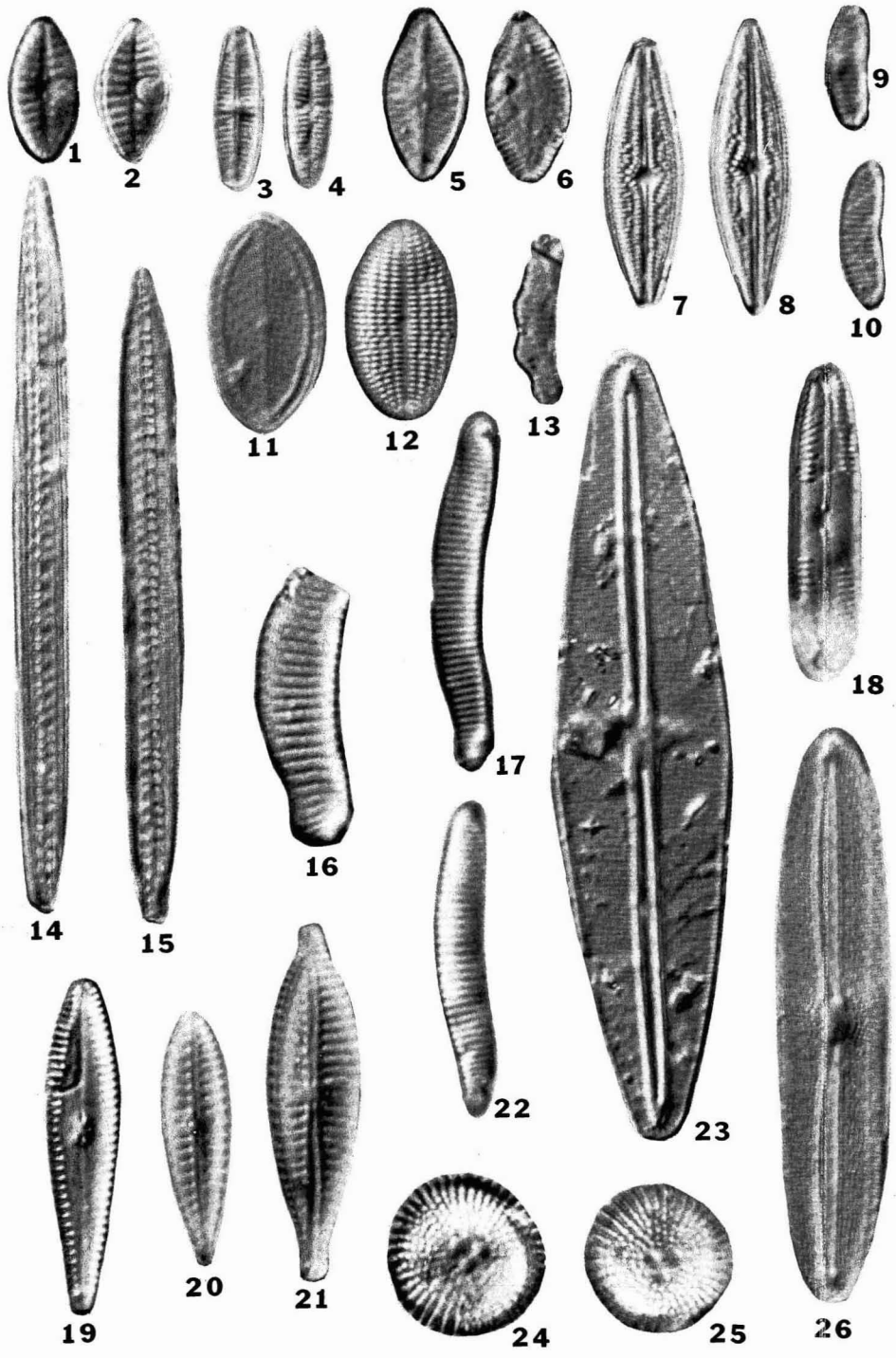

FIGURE 1. *1, 2, Achnanthes lanceolata*; *3, 4, Achnanthes linearis*; *5, 6, Achnanthes montana*; *7, 8, Anomoeoneis serians* var. *brachysira*; *9, 10, Eunotia curvata* var. *subarcuata*; *11, 12, Cocconeis placentula* var. *lineata*; *13, Eunotia polydentula*; *14, 15, Bacillaria paxillifer*, × 1260; *16, Eunotia praerupta* var. *inflata*; *17, 22, Eunotia tenella*; *18, Pinnularia leptosoma*; *19, Gomphonema brasiliense*; *20, Gomphonema parvulum*; *21, Gomphonema parvulum* var. *lagenula*: *23, Frustulia rhomboides*; *24, 25, Melosira roseana*; *26, Frustulia vulgaris* var. *elliptica*. All figures are × 2000 unless otherwise noted.

26–28 in 10 μm at the middle of valve, becoming more than 30 in 10 μm near ends. This was the most abundant taxon in our collection. It comprised 53.6% of the population.

BACILLARIA

Bacillaria paxillifer (O. Muell.) Hendey (Figure 1, *14*, *15*). Valve 72–82 μm long by 5–6.5 μm wide; fibulae not equidistant, 7–8 in 10 μm;striae 24–26 in 10 μm. This taxon was present as two intact valves and fragments in the Kilauea material.

COCCONEIS

Cocconeis placentula var. *lineata* (Erh.) Cleve (Figure 1, *11*, *12*). Valve 15 μm long by 8 μm wide; striae on both valves 22 in 10 μm. This taxon was represented by one complete valve and fragments in our material.

EUNOTIA

Eunotia curvata var. *subarcuata* (Naeg.) Grun. in V.H. (Figure 1, *9*, *10*). Valve lunate or arcuate, dorsal and ventral margins parallel, 7–10.5 μm long by 2.5–3 μm wide; striae 21–24 in 10 μm. This taxon was the most common *Eunotia* in our material. Our specimens were smaller than usual for this variety but fit quite well in other respects (Wahrer 1981). Some of our smaller specimens were nearly ovoid in shape, with poorly visible terminal nodules.

Eunotia polydentula (Brun.) Hust. (Figure 1, *13*). Valve 10.5 μm long by 3 μm wide; striae somewhat radiate, 20–22 in 10 μm. This *Eunotia* was present in the Kilauea material only as a single intact specimen and as broken fragments. Striae were very fine in our specimens.

Eunotia praerupta var. *inflata* Grun. (Figure 1, *16*). Valve about 28 μm long by 6 μm wide; striae 12 in 10 μm at the middle of valve, becoming 14–15 in 10 μm near ends. This taxon was present as a single broken valve in our material.

Eunotia tenella (Grun.) Cl. (Figure 1, *17*, *22*). Valve slightly swollen at the middle, 19–25.5 μm long by 3–4.5 μm wide; striae 15–18 in 10 μm at the middle of valve, becoming finer near ends. This taxon was present as five, or six complete valves in our material.

FRUSTULIA

Frustulia rhomboides (Ehr.) DeT. (Figure 1, *23*). Valve 42–55 μm long by 11–12 μm wide; transverse and longitudinal striae 28–30 in 10 μm. This taxon was the second most common in our material. It comprised approx. 20.4% of the Kilauea vent population. Only the nominate *F. rhomboides* occurred in the steam vent. Both *F. rhomboides* var. *saxonica* and *F. rhomboides* var. *capitata* are common in other Hawaiian localities.

Frustulia vulgaris var. *elliptica* Hust. (Figure 1, *26*). Valve 41 μm long by 9 μm wide, with rounded ends; transverse striae radiate at middle of valve, becoming convergent near ends, 38–40 in 10 μm; longitudinal striae 28–30 in 10 μm. Only a single valve of this taxon was observed in our material.

GOMPHONEMA

Gomphonema brasiliense Grun. (Figure 1, *19*). Valve 23 μm long by 5 μm wide; striae parallel in the center of the valve, becoming radiate near the ends, 15–16 in the middle of the valve, becoming somewhat finer near the ends. This taxon was present only as a single specimen in our material.

Gomphonema parvulum (Kuetz.) V.H. (Figure 1, *20*). Valve 18 μm long by 4.5 μm wide; striae 14–15 in 10 μm, somewhat finer at ends. This taxon was present in our material as a single valve. It was shaped as *G. parvulum* var. *micropus* but had finer striae.

Gomphonema parvulum var. *lagenula* (Kuetz.? Grun.) Hustedt (Figure 1, *21*). Valve 25 μm long by 6 μm wide; striae 13–14 in 10 μm. This taxon differs from the nominate by having knobbed ends. We saw only a single valve of this taxon, although it is common in other Hawaiian localities.

Gomphonema truncatum Ehr. Valve about

32 μm long by 9.5 μm wide; striae radiate 11–12 in 10 μm at the middle, becoming 12–14 at the basal pole. Only a single specimen was noted in our Kilauea material.

GYROSIGMA

Gyrosigma cf. *acuminatum* var. *gallica* Grun. (Figure 2, *40*). Valve 94.5 μm long by 13 μm wide; striae 30–31 in 10 μm, undulate at midvalve. Only a single specimen of this taxon was present in our Kilauea material. Our specimen had finer striae than is usual for this taxon, but otherwise fit the description well.

MELOSIRA

Melosira roseana Rabh. (Figure 1, *24*, *25*). Valve 11.5 μm in diameter; striae 14–16 in 10 μm; three prominent punctae present at midvalve. This taxon was present only as a single specimen in our material.

NAVICULA

Navicula contenta f. *biceps* (Arnott) Grun. (Figure 2, *31*). Valve 7–9 μm long by 2.5–3 μm wide; striae finer than 30 in 10 μm, often unresolved. This taxon was quite common in our Kilauea material; it is common in subaerial habitats in other parts of Hawaii as well.

Navicula mutica Kuetz. (Figure 2, *28–30*). Valve 11–27 μm long by 5–7.5 μm wide; striae 16–21 in 10 μm at the center, becoming somewhat finer at the ends. *Navicula mutica* was collected as several frustules from the Kilauea vent. Our specimens were quite variable in shape, and the striae were always fine.

Navicula muticoides Hust. (Figure 2, *33–34*). Valve 10–15 μm long by 5.5–7 μm wide; striae 24–30 in 10 μm. This species was present as several specimens in the Kilauea material. It is determined by the deflected proximal raphe ends and the near marginal isolated punctum.

Navicula radiosa var. *parva* Wallace (Figure 2, *27*). Valve 25 μm long by 4.5 μm wide; striae radiate 15–16 in 10 μm. Only a single specimen of this taxon was noted in our material.

Navicula species (Figure 2, *32*). Valve 19 μm long by 3.5 μm wide; striae unresolved. This taxon was represented by 4 or 5 valves in our material.

NITZSCHIA

Nitzschia frustulum var. *subsalina* Hust. (Figure 2, *35*). Valve 10 μm long by 2 μm wide; striae 28 in 10 μm; fibulae 14–16 in 10 μm. We saw only a single specimen of this *Nitzschia* in the Kilauea material. It is characterized by its fine striae and fine, equidistant fibulae.

Nitzschia minutula Grun. (Figure 2, *42*). Valve 23.5–26 μm long by 3 μm wide; striae 30–32 in 10 μm; fibulae equidistant, 13 in 10 μm near valve center, 15 in 10 μm near valve ends. This species was present as three valves in our material. We have placed it into *N. minutula* on the basis of the equidistant fibulae and fine striation.

Nitzschia palea (Kuetz.) W. Sm. (Figure 2, *38*). Valve about 24 μm long by 5.5 μm wide; striae unresolved; fibulae 12–13 in 10 μm. *Nitzschia palea* was represented by two broken valves in the Kilauea material.

Nitzschia pellucida f. *minores* Cleve-Euler (Figure 2, *39*). Valve 21 μm long by 7 μm wide; striae 32–34 in 10 μm; fibulae 19–20 in 10 μm. This *Nitzschia* was present only as a single specimen in the Kilauea material.

Nitzschia species (Figure 2, *37*). Valve linear lanceolate, with subcapitate apices, 74–86 μm long by 4–5 μm wide; striae distinctly punctate, forming vertical and horizontal rows, 22–24 in 10 μm; keel submarginal; fibulae unevenly spaced near valve center, 7–8 in 10 μm; central fibula large, slightly displaced toward valve center. We have seen this taxon only at the Kilauea site during our Hawaiian studies. It is unusual due to its punctate striae, which are aligned to form horizontal and vertical striae. We have previously reported (Fungladda, Kaczmarska, and Rushforth 1983) that this taxon is similar in some respects to several of the lanceolate *Nitzschia* species, including *N. intermedia*, *N. linearis*, and *N. subtilis*, but differs from each of these in certain respects. Our

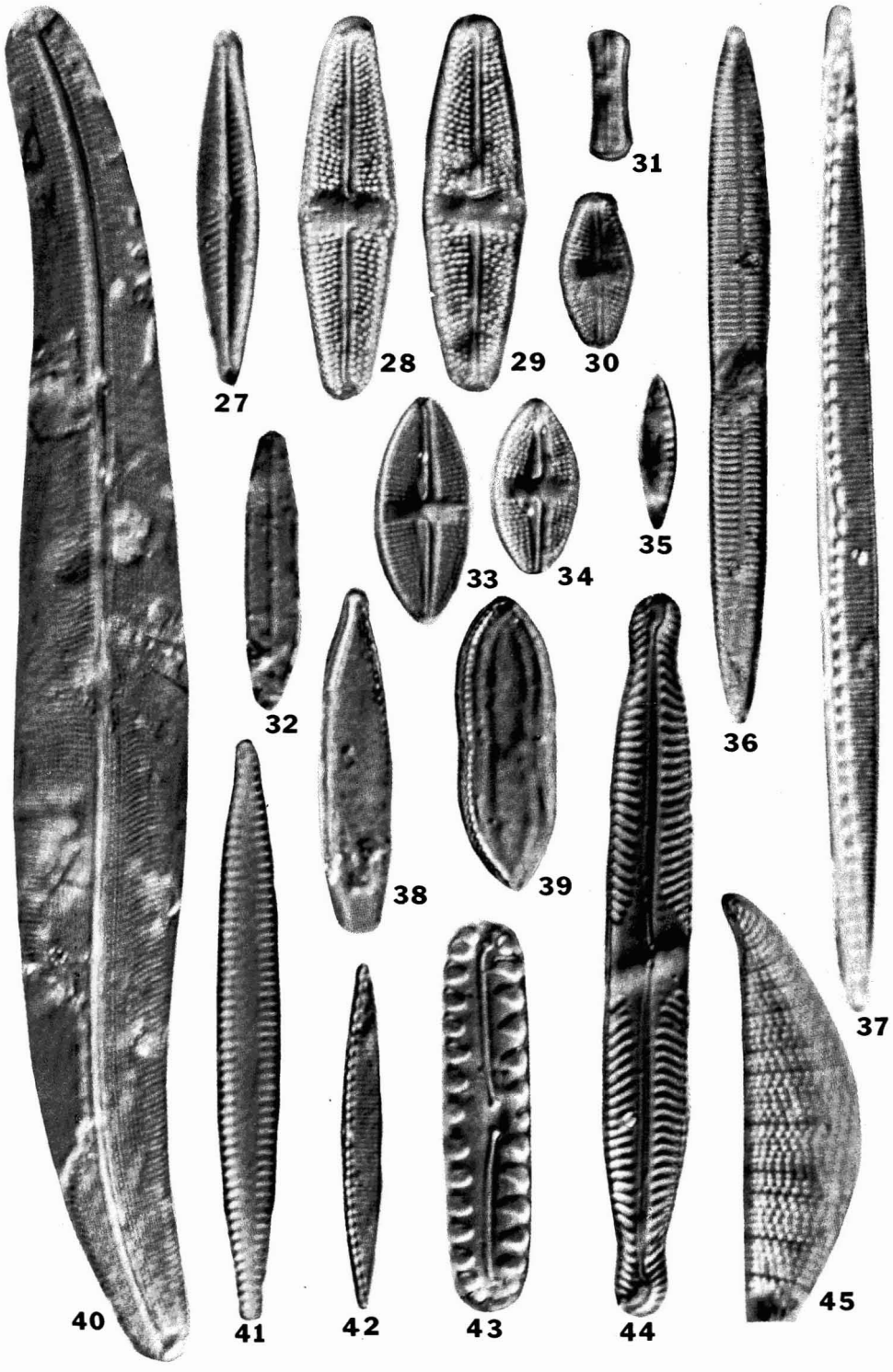

FIGURE 2. *27*, *Navicula radiosa* var. *parva*; *28–30*, *Navicula mutica*; *31*, *Navicula contenta* f. *biceps*; *32*, *Navicula* species; *33*, *34*, *Navicula muticoides*; *35*, *Nitzschia frustulum* var. *subsalina*; *36*, *Synedra ulna*, ×1000; *37*, *Nitzschia* species; *38*, *Nitzschia palea*; *39*, *Nitzschia pellucida* f. *minores*; *40*, *Gyrosigma* cf. *acuminatum* var. *gallica*; *41*, *Synedra fasciculata* var. *truncata*; *42*, *Nitzschia minutula*; *43*, *Pinnularia borealis* var. *rectangularis*; *44*, *Pinnularia termitina*; *45*, *Rhopalodia gibberula* var. *vanheurckii*. All figures are ×2000 unless otherwise noted.

specimens are within the reported range of variability of *N. gandersheimiensis* (Lange-Bertalot and Simonsen 1978), although the arrangement of striae and central fibulae in ours deviate from that taxon. *Nitzschia miramarensis* Hagelstein (1938: 398) appears to be very similar to our specimens. Ours differ by being smaller and having somewhat finer striae than that taxon.

PINNULARIA

Pinnularia borealis var. *rectangularis* Carlson (Figure 2, *43*). Valve 22–36 μm long by 5.5–8.5 μm wide; striae 4–6 in 10 μm. *Pinnularia borealis* var. *rectangularis* was present in moderate numbers in our Kilauea material but was less abundant than *P. termitina*.

Pinnularia leptosoma (Grun.) Cl. (Figure 1, *18*). Valve 21–22 μm long by 4 μm wide; striae 20 in 10 μm, becoming somewhat finer near ends. This taxon has fine striae for a *Pinnularia* and may be separated from *Caloneis bacillum*, which is also present in the Hawaiian flora, on the basis of the striae being coarser and tending to become more convergent in the former. This taxon was quite rare in our material.

Pinnularia termitina (Ehr.) Patrick (Figure 2, *44*). Valve 31–57 μm long by 4.5–5.5 μm wide; striae 11–15 in 10 μm. *Pinnularia termitina* was quite abundant in our Kilauea material, comprising about 6.7% of the population.

RHOPALODIA

Rhopalodia gibberula var. *vanheurckii* O. Muell. (Figure 2, *45*). Valve about 35 μm long by 7.5 μm wide; costae 4–5 in 10 μm, somewhat finer near ends; striae 19–20 in 10 μm. This taxon was present at the Kilauea site as a single specimen.

SYNEDRA

Synedra fasciculata var. *truncata* (Greg.) Patrick (Figure 2, *41*). Valve 39–42 μm long by 4.5–5 μm wide; striae 13–14 in 10 μm, becoming somewhat finer near ends. We observed this taxon as two valves in our material.

Synedra ulna (Nitz.) Ehr. (Figure 2, *36*). Valve 101–120 μm long by 7.5–8.5 μm wide; striae 9–11 in 10 μm. *Synedra ulna* was seen in our material as one intact and three broken valves.

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