

## A PRELIMINARY REPORT ON THE DIATOMS OF THE HOT SPRINGS OF TAIWAN<sup>(1)</sup>

TSANG-PI CHANG

In 1965-66 a study was made of the algal flora of the hot springs of Taiwan. There are approximately forty hot-springs on this island. Almost all of them are located in the higher mountains, where they are not easily reached for observation. Twelve of these hot-springs have been studied for their phycological flora and are listed below:

Name of Hot-spring	Location	County	Kind of hot-spring
Wu-lai	24°52', 121°33'	Taipei	Alkaline
Yang-ming-shan	25°09', 121°33'	Taipei	Acid
Hsin-pei-tou	25°08', 121°30'	Taipei	Simple, sulphureous, and alum-vitriol
Chin-shan	25°13', 121°38'	Taipei	?
Rua-shan	24°01', 121°09'	Nantou	Alkaline
Chiao-shi	24°49', 121°46'	I-lan	Simple
Jui-sui	23°30', 121°22'	Hwalien	Salt (H <sub>2</sub> S)
Antung	23°18', 121°20'	Hwalien	Alkaline
Chih-pen	22°42', 121°01'	Taitung	Alkaline
Yuan-shan	24°45', 121°42'	I-lan	Simple
Kuan-tzu-ling	23°21', 121°30'	Chiayi	Alkaline (halogenic)
Ssu-chung-chi	22°05', 121°45'	Pingtung	Alkaline

The blue-green algae and diatoms are comparatively abundant in these hot springs and this is also true for hot springs in other countries of the world. Actually, diatoms are less important than the blue-green algae, because they do not become truly colonial in these sites. They are always scattered among the other algae, except in the ditches near the spring source where we often find pure colonies appearing brownish-red in color. It may be that they appear to exist in higher temperatures than other algae, but their chromatophores were not observed in most samples studied, this causes the author to think they cannot tolerate temperatures higher than 65°C (which was the average temperature of all hot springs examined) and so they have left their valves there as deposits. Judging from some of the kinds found at Wu-lai, we think that they were carried from normal temperature water into these higher temperature sites by floods during heavy rains and typhoons. Ordinarily, the water-level in the streams and rivers do not reach very high upon the banks. This condition exists at Yang-ming-shan, Chiao-shi, An-tung, Ssu-chung-chi, Chih-pen and Rua-shan. The hot springs at Hsin-pei-tou, Chin-shan, Rua-shan,

(1) This paper is based upon the author's M.S. thesis. The author is very thankful to Dr. Charles E. DeVol for his guidance in the preparation of this manuscript.

Jui-shi, Chih-pen (hillside), Yuan-shan and Kuan-tzu-ling are somewhat farther away from streams and rivers, but they can be flooded by heavy rains and by water from the terraced rice fields above.

The diatoms at Wu-lai were more abundant than in other springs; among the more common forms were: *Synedra ulna*, *Diploneis puella*, *Pinnularia* spp., *Navicula cuspidata* var. *ambigua* and the filamentously colonial form *Fragilaria construens* var. *ventur*. At Chin-shan *Amphora normani* and *Nitzschia frustulum* var. *perminuta* were dorminants. The particular one or two diatoms considered to be more important in the other springs were *Achnanthes exigua* and its variety at Chiao-shi, *Pinnularia interrupta* and *Nitzschia dissipata* at Yang-ming-shan, *Denticula elegans* and *D. thermalis* at Rua-shan and *Anomoeoneis exilis* at An-tung. Few diatoms were found in the other hot-springs. Diatoms were not found at Kuan-tzu-ling or Hsin-pei-tou. In the thermal cites studied there were 44 species, varieties and forma observed. Most of them are new additions to the records of Taiwan's phycological flora.

An annotated list of Taiwan thermal diatoms and their important characters follows:

### DIVISION BACILLARIOPHYTA

#### Class BACILLARIOPHYCEAE

Common name: Diatoms, 矽藻.

Character:

1. Vegetative cells: uninucleate, without flagella; unicellular or colonial; they have silicified cell walls (frustule) of two valves: epivalve (epitheca) and hypovalve (hypotheca); and are seen in two views: valve and girdle. The valves have various ornamentations of striae and punctae, and have different shapes of nodules and raphes.
2. Pigments: chlorophyll a and c,  $\beta$  and  $\epsilon$  carotenes, 5 xanthophylls, diatomine and others.
3. Reserve foods: fats (oil droplets) and volutin or leucosin, but never starch.
4. Motility: without flagella, but some move by the streaming of cytoplasm; some are plankton and carried about by water currents.
5. Reproduction: by cell division, auxospores, statospores (cysts or endospores) and microspores (mostly in marine species)
6. Distribution: in fresh and salt waters, attached or free-floating; also in cold waters or hot-springs.

Diatoms are divided into two orders: CENTRALES and PENNALES.

#### Key to the orders of diatoms

1. Valves mostly round, with radial or concentric ornamentation from a central point; radially symmetrical, with marginal spines; raphe or pseudoraphe none; cell immobile ..... I. Centrales

- 1. Valves rarely round, with bilateral ornamentation; bilaterally symmetrical, without marginal spines; raphe or pseudoraphe present; cells with raphe, mobile .....II. Pennales

I Order CENTRALES

Only the one family, Coscinodiscaceae has been found in the hot springs of Taiwan.

Family COSCINODISCACEAE

Cell discoid, solitary or in filamentous colonies; ornamentation of valve radial; without marginal spines or ocelli; girdles with or without sculptures.

Key to the genera in Taiwan spas

- 1. Cells cylindrical, closely united into long filamentous colonies; valves irregularly ornamented, with punctae or none, and with or without marginal spines.....1. *Melosira*
- 1. Cells discoid, drum-shape or cylindric, solitary and free-floating, rarely in chains; valves radially punctate and marginally short-spined.....2. *Stephanodiscus*

1. MELOSIRA C. A. Agardh 1824

Only one species has been found in the Taiwan spas.

**Melosira varians** C. A. Ag.

Cells cylindrical, closely united into long chains, 8-35×9-13 μ; sulcus absent; valves convex, slightly punctate; girdles very weakly punctate, appearing smooth; chromatophores numerous, small discoid.

Taiwan: Wu-lai, 40°C.

Distribution; Around ten spas in Japan (Kobayashi, 1957, p. 71).

References: Hustedt 1930, p. 85, fig. 41; Tiffany and Britton 1951, p. 221, pl. 59, fig. 673; Mizuno 1964, p. 128, pl. 47, figs. 8, 9.

2. STEPHANODISCUS Ehrenberg 1845

Only one species from Taiwan spas.

**Stephanodiscus Hantzschii** Grunow

Cells drum-shaped, 8-20 μ in diameter, free or in short chains; valves briefly punctate; small spines alternating with striations; chromatophores numerous, small.

Taiwan: Wu-lai 55°C.

Distribution: In fresh, brackish waters of Europe, America and Japan.

References: Hustedt 1930, p. 110, fig. 87; Tiffany and Britton 1951, p. 222, pl. 60, fig. 679.

II Order PENNALES

Fourteen genera were found in the Taiwan spas during our studies, later a fifteenth genus, *Surirella* was added to the Taiwan flora.

## Key to the genera of the order Pennales of the Taiwan thermal diatoms

1. Valves longitudinally asymmetric .....2
1. Valves longitudinally symmetric.....5
2. Raphe within a marginal keel.....14. *Nitzschia*
2. Raphe not within a marginal keel.....3
3. Valves with transverse costae.....12. *Rhopalodia*
3. Valves without transverse costae.....4
4. Cells with parallel sides in girdle view .....10. *Cymbella*
4. Cells broadly elliptical in girdle view .....11. *Amphora*
5. Valves transversely asymmetric .....9. *Gomphonema*
5. Valves transversely symmetric .....6
6. Girdle view asymmetric.....7
6. Girdle view symmetric.....8
7. Girdles longitudinally bent or bowed .....4. *Achnanthes*
7. Girdles transversely bent or bowed.....3. *Cocconeis*
8. Colony formation frequent .....1. *Fragilaria*
8. Colony formation rare or absent .....9
9. Cells connected into pairs or chains.....10
9. Cells always solitary and free-floating.....11
10. Valves with transverse striae .....2. *Synedra*
10. Valves with transverse costae .....13. *Denticula*
11. Axial area band-like, expanded to poles.....12
11. Axial area none.....13
12. Cells completely elliptical .....6. *Diploneis*
12. Cells lanceolate, with polar ends .....5. *Anomoeoneis*
13. Valves with transverse costae .....8. *Pinnularia*
13. Valves with transverse striae or row of punctae .....7. *Navicula*

## Suborder I FRAGILARINEAE

## Family FRAGILARIACEAE

Two genera, *Fragilaria* and *Synedra*, of this family are found in the Taiwan spas.

1. Genus **FRAGILARIA** Lynoye 1819; Rabenhorst 1864

Key to Taiwan thermal species and variety

1. Cells united into ribbon-like chains; valves naviculoid..2. *F. construens* var. *ventur*
1. Cells always solitary or free-floating; valves rod-like .....2
2. Cells long rod-like .....1. *F. capucina*
2. Cells short rod-like .....3. *F. intermedia*

**1. *Fragilaria capucina* Desmazières**

Cells  $5-12 \times 7-25 \mu$ , united in a long ribbon-like chain, mostly zigzag, sometimes flat in short colonies; valves greatly broadened medially, almost cruciform, with lens-like pseudoraphe; bilateral striation 14-17 in  $10 \mu$ .

The sample cells are almost always found free and single.

Taiwan: Wu-lai 40°C.

Distribution: Very common in fresh-waters.

References: Hustedt 1930, p. 138, fig. 126; Tiffany and Britton 1951, p. 234 pl. 62, fig. 698; Mizuno 1964, p. 135, pl. 49, fig. 10.

**2. *Fragilaria construens* var. *ventur* (Ehrenberg) Grunow**

Cells  $5-12 \times 7-25 \mu$ , united in a long ribbon-like chain, mostly zigzag, sometimes flat in short colonies; valves greatly broadened medially, almost cruciform, with lens-like pseudoraphe; bilateral striations 14-17 in  $10 \mu$ .

There are two types of this species; one is slender but longer than the other.

Taiwan; Wu-lai 40°C; Rua-shan 59°C.

Distribution; Very common in freshwaters.

References: Hustedt 1930, p. 141, fig. 138; Tiffany and Britton 1951, p. 234, pl. 62, fig. 697; Mizuno 1964, p. 135, pl. 49, figs. 5-7.

**3. *Fragilaria intermedia* Grunow**

Cells  $2.5-5 \times 15-60 \mu$ , always united into a ribbon-like chain; valves linear, with headed poles, with a distinct pseudoraphe; central area bright at one side, while the other has striae; bilateral striae 9-13 in  $10 \mu$ .

Sample cells were found in solitary and free condition.

Taiwan. Wu-lai 54°C.

Distribution: Widely distributed but not common in fresh-waters.

References; Hustedt 1930., p. 139, fig. 130; Mizuno 1964, p. 135, pl. 49, fig. 9.

**2. Genus *SYNEDRA* Ehrenberg 1930**

Only one species was found in Taiwan spas.

***Synedra ulna* (Nitzsch) Ehrenberg**

Cells  $5-9 \times 50-350 \mu$ , solitary or planktonic; linear in girdle view; valves linear to lanceolate, very gradually narrowed toward the rounded or headed poles; pseudoraphe narrowly linear, with central area varying, but absent in sample cells, transverse striae 8-12 in  $10 \mu$ .

Taiwan: Wu-lai 40°C.

Distribution: Hot-springs 26°C, 28°C of Japan (Yoneda 1942, p. 95; Emoto and Yoneda 1941, p. 10; Kobayashi 1957, p. 73). Very common in various kinds of water, freshwater to marine. Many variations.

References: Hustedt 1930, p. 151, figs. 158, 159; Tiffany and Britton 1951, p. 237, pl. 63, fig. 713; Mizuno 1964. p. 137. pl. 50, figs. 1-11.

## Suborder II ACHNANTHINEAE

## Family ACHNANTHACEAE

Two genera *Cocconeis* and *Achnanthes* were found in Taiwan spas.

3. Genus **COCCONEIS** Ehrenberg 1835; Grunow 1868.

Cells curved transversely in girdle view, free or epiphytic; septa incomplete; central band absent; valves elliptical, epivalve with a pseudoraphe, hypovalve with median raphe, straight or sigmoid, with central and polar nodules and striae; chromatophore single, laminate.

Only one plant was found in Taiwan spas.

***Cocconeis placentula* var. *klinoraphis*** Geitler

Cells elliptical,  $16 \times 27 \mu$ ; valves flat, transverse striae sometimes radial, 20 in  $10 \mu$  and always crossed by longitudinal striations; central area round, small.

Taiwan; Wu-lai  $40^\circ\text{C}$ .

Distribution: In hot-springs of Japan [Kobayashi 1957, p. 72; p. 236; Mizuno 1964, p. 143, pl. 52, fig. 3 (a, b)].

Reference: Hustedt 1930, p. 190, fig. 263.

4. Genus **ACHNANTHES** Bory 1822

Cells free or united into a ribbon-like chain, transversely curved in girdle view like "<", with a median band; valves linear-lanceolate or elliptical, with raphe or pseudoraphe or both, central area transversely widened into a stauros; transverse striations.

## Key to Taiwan thermal species and variety

- 1. Valve bilaterally symmetric.....2
- 1. Valve bilaterally asymmetric.....3. *A. minutissima*
- 2. Striations short and distinct.....1. *A. exigua*
- 2. Striations dull or none .....3
- 3. Cells less than  $10 \mu$  in length .....4. *A. minutissima* var. *cryptocephala*
- 3. Cells more than  $20 \mu$  in length .....2. *A. microcephala*

1. ***Achnanthes exigua*** Grunow

Cells  $5-6 \times 5-20 \mu$ , elliptical, with headed poles; raphe longitudinally straight, parallel striae transverse, 22 in  $10 \mu$ ; central area narrow, bandlike, smooth.

Sample cells  $6-10 \mu$  in length,  $5 \mu$  in breadth; slightly elliptical to rounded; flattened, capitate, slightly protruding at poles; central area in a "cross" form. These cells are especially found in Chiao-shi, accompanying the normal type; they are close to the variety found in India (Skvortzow 1935)

Taiwan: Wu-lai  $40^\circ\text{C}$ ; Rua-shan  $53^\circ, 59^\circ\text{C}$ ; Chin-shan  $60^\circ\text{C}$ ; and Chiao-shi  $48^\circ\text{C}$ .

Distribution; In hot-springs of Japan (Yoneda 1942; Emoto and Yoneda 1942; Kobayashi 1957; Mizuno 1964, p. 142, pl. 51, fig. 12); in Western India spas 41°C (Thomas and Gonzálves 1963). The species is a representative of thermal algae, and is common in freshwaters.

References: Hustedt 1940, p. 201, fig. 286; Skvortzow 1935, p. 182, pl. 1, fig. 3.

**2. *Achnanthes microcephala* (Kützing) Cleve**

Cells long-elliptical, 2-3×8-26 μ, gradually tapering, with headed poles; epivalve having a raphe, central area very narrow, hypovalve having a pseudoraphe, central areas several; striae 26-36 in 10 μ.

Striae of sample cells was hard to observe; they seemed to have disappeared.

Taiwan: Chin-shan 60°C.

Distribution: Very common in freshwaters:

References: Hustedt 1930, p. 198, fig. 274; Tiffany and Britton 1951, p. 242, pl. 64, fig. 726; Mizuno 1964, p. 141, pl. 51, fig. 5.

**3. *Achnanthes minutissima* (Kützing) Cleve.**

Cells 2-5×5-40 μ; transversely curved in girdle view like “◁”, median band (or girdles) distinct; valves lanceolate, gradually tapering toward rounded poles; epivalve with narrow pseudoraphe, central area absent; hypovalve with delicate thread-like raphe, central area small; transverse striae 33-35 in 10 μ.

Taiwan: Wu-lai 40°C.

Distribution: Very common in freshwaters: lakes, ponds, rivers and brooks.

References: Hustedt 1930, p. 198, fig. 274 a, b, c; Tiffany and Britton 1951, p. 242, pl. 64, fig. 727; Mizuno 1964, p. 142, pl. 51 fig. 11.

**4. *Achnanthes minutissima* var. *cryptocephala* Grunow**

Cells 2-2.5×9-12 μ; valve broader in median part and more attenuate at poles; striations dull; other characteristics like the preceding type.

Taiwan: Jui-sui 35°C.

Distribution: Common in freshwaters.

References; Hustedt 1930, p. 198, fig. 275; Skvortzow 1938, p. 289

Suborder III NAVICULINEAE

Key to Taiwan thermal families

- 1. Valve transversely asymmetric.....2
- 1. Valve transversely symmetric.....3
  - 2. Raphe centrally linear .....3. Cymbellaceae
  - 2. Raphe marginally keeled .....4. Nitzschiaceae
- 3. Valve longitudinally asymmetric .....2. Gomphonemataceae
- 3. Valve longitudinally symmetric .....1. Naviculaceae

## Family 1 NAVICULACEAE

Four genera: Anomoconeis, Diploneis, Navicula and Pinnularia were found in Taiwan spas.

5. Genus **ANOMOEONEIS** Pfitzer 1871

Cells always free, lanceolate or naviculoid; rectangular in girdle view; valves gradually tapering toward headed poles; raphe centrally straight, striations not distinct; no intercalary bands; chromatophores only one and laminate.

Key to Taiwan thermal plants

1. Valves regularly to rhombo-lanceolate.....1. *A. exilis*  
 1. Valves naviculoid.....2. *A. serians* var. *brachysira* f. *thermalis*

1. **Anomoconeis exilis** (Kützing) Cleve

Cells 4-6×15-35  $\mu$ ; valves lanceolate, with capitate poles; raphe straight, central area small, circular; transverse striations radial, about 30 in 10  $\mu$ , crossed by longitudinal striations.

Taiwan: An-tung 58°C; Wu-lai 52°.

Distribution: Common in freshwaters, ponds or lakes.

References: Hustedt 1930, p. 264, fig. 429; Skvortzow 1938a, p. 211, fig. 1 (34, 35, 36); Tiffany and Britton 1951, p. 246, pl. 65, fig. 739.

2. **Anomoconeis serians** var. **brachysira** forma **thermalis** (Grunow) Hustedt

Cells 3.5-6×12-30  $\mu$ ; valves lanceolate, gradually tapering toward acute poles; raphe straight, central area circular; transverse striations slightly radial, 20-24 in 10  $\mu$ .

Striations of sample cells were hard to observe.

Taiwan: Wu-lai 40°C.

Distribution: Northern alpine regions.

References: Hustedt 1930, p. 264, fig. 428; Skvortzow 1938a, p. 211 fig. 1 (21); Tiffany and Britton 1951, p. 246, pl. 65, fig. 738—the type species.

6. Genus **DIPLONEIS** Ehrenberg 1844

Cells free, solitary, rectangular in girdle view; valves elliptical or linear with a median constriction; central nodule transversely quadrate; central area extending toward poles like horns, with a longitudinal furrow; transverse costae or rows of punctae, sometimes radial, often crossed by longitudinal costae or punctae; chromatophores two.

Only one species was found in Taiwan spas.

**Diploneis puella** (Schumann) Cleve

Cells 6-14×13-27  $\mu$ , elliptical; central area large and quadrate, horns distinct, furrow narrow; transverse costae delicate, slightly radial, 14-18 in 10  $\mu$ , with an intermediate space finely punctae; longitudinal costae indistinct.



Two forms  $10-15 \times 32 \mu$  and  $9-12 \times 16-20 \mu$  were found in samples.

Taiwan: Wu-lai 40°C; Chin-shan 60°C; Jui-sui 35°C; Yuan-shan 40°C.

Distribution; Common along with other algae and freshwater plants.

References; Hustedt 1930, p 250, fig. 394; Tiffany and Britton 1951, p. 249, pl. 65, fig. 751.

7. Genus NAVICULA Bory 1822; emend. Cleve 1894

Cells always solitary or free-floating, sometimes aggregated into radiating clusters, rectangular in girdle view, with smooth spaces; valves elongate, gradually tapering toward headed poles; axial field distinct, straight raphe, nodules small; transverse striation, sometimes medially radial; two laminate chromatophores, rarely four to eight.

Key to Taiwan thermal species and varieties

- 1. Transverse striations parallel .....2
- 1. Transverse striations radial .....3
  - 2. Central area band-like .....4. *N. Lagerheimii* var. *intermedia*
  - 2. Central area circular .....4
- 3. Cells less than  $25 \mu$  in length .....7
- 3. Cells more than  $45 \mu$  in length .....7. *N. rhyncocephala*
  - 4. Valve long naviculoid or lanceolate .....5
  - 4. Valve elliptical or rounded .....6
- 5. Raphe linear, furrow indistinct; striations distinctly parallel .....3. *N. halophila*
- 5. Raphe in furrow; striations transverse and crossed by longitudinal punctae, but always indistinct .....2. *N. cuspidata* var. *ambigua*
- 6. Cells rounded .....5. *N. Lagerheimii* var. *ovata*
- 6. Cells elliptical .....1. *N. atomus*
- 7. Valve elliptic-lanceolate .....6. *N. menisculus*
- 7. Valve linear .....8. *N. cryptocephala*

1. *Navicula atomus* (Naegeli) Grunow

Celle  $2-4 \times 4-8 \mu$ ; valves minute, elliptical, with short and broad poles.

Taiwan: Chin-shan 60°C.

Distribution: Common in freshwaters.

References: Hustedt 1930, p. 288, fig. 484; Skvortzow 1938, Philip. J. Sci. 66(1): 55, pl. 2, fig. 25.

2. *Navicula cuspidata* var. *ambigua* (Ehrenberg) Cleve

Cells  $17- \times 50-170 \mu$ ; valve lanceolate with rostrate-capitate poles; striations  $17-19$  in  $10 \mu$ .

Taiwan: Wu-lai 40°C; 45°C; Rua-shan 35°C, 59°C.

Distribution: Common, a fresh-water species.

References: Hustedt 1930, p. 268, fig. 434; Skvortzow 1935, p. 181, pl. 1, fig. 8; Mizuno 1964, p. 160, pl. 59, fig. 20.

**3. *Navicula halophila* (Grunow) Cleve**

Cells 8-16×25-140  $\mu$ , naviculoid; axial area linear, narrow; central area small; transverse striations parallel, 17-19 in 10  $\mu$ .

Taiwan; Wu-lai 40°C.

Distribution: Common in inland lakes; in hot-springs of Japan [Negoro 1942, p. 400, fig. (8); Kobayashi 1957, p. 236].

Reference: Hustedt 1930, p. 268, fig. 436.

**4. *Navicula Lagerheimii* var. *intermedia* Hustedt**

Cells 18-21×18-21  $\mu$ ; valve lanceolate, with distinct broad margins; axial area narrow; central area quadrate to circular; striations radiate, distinctly punctate.

Taiwan: Chin-shan 60°C.

Distribution: Common in freshwater, associated with blue-green algae.

Reference: Skvortzow 1938b, p. 446, pl. 1, figs. 3, 4, and 32. (= *N. pseudoseminulum* Skv. and var. *curta* Skv. Skvortzow 1935, p. 183, pl. 1, figs. 18, 19).

**5. *Navicula Lagerheimii* var. *ovata* Skvortzow**

Cells 5-7×8.5-10  $\mu$ ; valve ovate, slightly rounded at poles; striations 18-20 in 10  $\mu$ .

Sample cells always with a smooth space at the left side of valve, sometimes striations costae instead of punctae, was thought to be a new forma.

Taiwan: Chin-shan 60°C; Chiao-shi 48°C.

Distribution: Not common; subaerial (Skvortzow 1938b).

Reference: Skvortzow 1938b, p. 446, pl. 1, figs. 5, 6, 24.

**6. *Navicula menisculus* Schumann**

Cells 8-12×18-50  $\mu$ ; valve broadly lanceolate with truncate rounded poles; striations radiate, 10-12 in 10  $\mu$ .

Taiwan: Chin-shan 60°C.

Distribution: Not common, in mud of a channel, and in slightly salty waters. In hot-springs of Japan (Kobayashi 1957, p. 72; Mizuno 1964, p. 157, pl. 58, fig. 13).

References: Hustedt 1930, p. 301, fig. 517; Skvortzow 1935, p. 181, pl. 1, fig. 10.

**7. *Navicula rhyncocephala* Kützing**

Cells 10-13×35-60  $\mu$ ; valve lanceolate with slightly capitate poles; central area round; transverse striations, medially radial, convergent at the poles, 18-12 in 10  $\mu$ .

Taiwan: Wu-lai 40°C.

Distribution: Common in fresh-waters and brackish waters. In hot-springs of Japan (Kobayashi 1957, p. 72).

References: Hustedt 1930, p. 296, fig. 501; Skvortzow 1935, pl. 181, pl. 1, fig. 10; Tiffany and Britton 1951, p. 255, pl. 67, fig. 782.

8. *Navicula crytocephala* Kützing

Cells 5-7×20-40 μ; valve lanceolate with somewhat capitate poles; central area elongated transversely; striations 16-18 in 10 μ, fine medially radial and polarly convergent.

Taiwan: Ssu-chung-shi 38°C.

Distribution: Hokkaido 30°C, of Japan; and other spas (Emoto and Yoneda 1941, p. 23; Yoneda 1942, p. 98; Kobayashi 1957, p. 71, p. 235). In brackish waters, common.

References: Hustedt 1930, p. 295, fig. 496; Tiffany and Britton 1951, p. 255, pl. 67, fig. 767.

8. Genus PINNULARIA Ehrenberg 1840

Cells free, rarely in short filamentous colonies; symmetric, rectangular in girdle view, girdle distinctly smooth, but intercalary bands absent; valve medially inflated or undulate, with rounded poles; axial broad, always expanded both medially and polarly; raphe straight or sigmoid; costae radial or transverse; chromatophores two, laminate.

Key to Taiwan thermal species.

- 1. Cells more than 50 μ in length; striations costae or tube-like; central area circular .....1. *P. interrupta*
- 1. Cells less than 48 μ in length; striations linear; central area band-like.....2. *P. Kneuckeri*

1. *Pinnularia interrupta* W. Smith

Cells 8-16×140 μ; valves rhomboid-lanceolate, with an expanded, headed poles; axial area narrowly linear; central area small; striations parallel, convergent at the poles, 17-19 in 10 μ.

Taiwan: Wu-lai 40°C.

Distribution: Common in freshwaters and salty waters.

References: Hustedt 1930, p. 317, fig. 573; Mizuno 1964, p. 156, pl. 57, fig. 9.

2. *Pinnularia Kneuckeri* Hustedt

Close to the former species, but shorter in length; raphe very narrow; central area band-like.

Taiwan: Chih-pen 38°C; Yang-ming-shan hot-spring.

Distribution: Egypt; hot-springs of Japan (Kobayashi 1957, p. 71; p. 73)

Reference: Kobayashi 1957, p. 71, figs. G, H.

Family 2 GOMPHONEMATACEAE

Only one genus Gomphonema was found in Taiwan spas.

9. Genus **GOMPHONEMA** C. A. Agardh 1824

Cells usually epiphytic with a gelatinous stalk, sometimes attached or solitary or free-floating; transversely asymmetric in both views, girdles smooth; valves cuneate, clavate, lanceolate, with same or different sized poles; striations transverse; central area with a dot; chromatophore one.

Key to Taiwan thermal species and varieties

- |                                       |                                               |
|---------------------------------------|-----------------------------------------------|
| 1. Valve transversely asymmetric..... | 2                                             |
| 1. Valve transversely symmetric ..... | 3                                             |
| 2. Poles of same size.....            | 1. <i>G. angustatum</i> var. <i>obtusatum</i> |
| 2. Poles of different sizes.....      | 2. <i>G. angustatum</i> var. <i>producta</i>  |
| 3. Valve cuneate .....                | 3. <i>G. augur</i> var. <i>Gautieri</i>       |
| 3. Valve lanceolate.....              | 4. <i>G. parvulum</i>                         |

**1. Gomphonema angustatum** var. **obtusatum** (Kützing) Van Heurck

Cells  $5-6 \times 12-45 \mu$ ; one part of valve expanded and the other lanceolate, girdle view cuneate; one pole is more headed than the other.

Taiwan: Wu-lai 40°C.

Distribution: In freshwaters.

Reference: Tiffany and Britton 1951, p. 271, pl. 72, fig. 843.

**2. Gomphonema angustatum** var. **producta** Grunow

The size of one pole is twice as large as the other; other characteristics are just as the preceding.

Taiwan: Wu-lai 40°C.

Distribution: Same as the former.

Reference: Hustedt 1930, p. 373, fig. 693.

Species type: Hustedt 1930, p. 373, fig. 690; Tiffany and Britton 1951, p. 271, pl. 72, fig. 842; in spas of Japan (Mizuno 1964, p. 163).

**3. Gomphonema augur** var. **Gautieri** Van Heurck

Cells  $5-6 \times 25-70 \mu$ ; shaped like a pan; central area a distinct dot.

Taiwan: Chiao-shi 42°C.

Distribution: Commonly found in freshwaters.

References: Hustedt 1930, p. 372, fig. 689; Mizuno 1964, p. 162, pl. 60, fig. 9.

**4. Gomphonema parvulum** (Kützing) Grunow

Cells  $4-7 \times 12-3 \mu$ ; valves clavate-lanceolate; axial area narrow; central area small, with an isolated dot; transverse striations slightly radial, 14-16 in  $10 \mu$ .

Taiwan: Wu-lai 40°C.

Distribution: In hot-springs or Japan [Yoneda 1942, p. 99, fig. 4(5); Kobayashi 1957, p. 72, 236]; in Western Indian spas (Thomas and Gonzalves 1963); common in still waters.

References: Hustedt 1930, p. 372, fig. 713a; Tiffany and Britton 1951, p. 272, pl. 72, fig. 838.

Family 3 **CYMBELLACEAE**

Three genera: *Cymbella*, *Amphora* and *Rhopalodia* were found in Taiwan spas.

10. Genus **CYMBELLA** C. A. Agardh 1830

Cells free or attached to some object with a gelatinous stalk, rectangular in girdle view, and the smooth girdles without intercalary bands; valves asymmetric; axial area wide or small, narrow; central area with an isolated dot or without it; raphe curved, with nodules; transverse striations radiate; chromatophore one.

Only one species was found in Taiwan spas.

***Cymbella turgida*** Gregory

Cells 9-25×30-100 μ; valves lunate, with rounded poles; raphe excentric, with central and polar nodules; transverse striations 7-9 in 10 μ.

Taiwan: Wu-lai 40°C.

Distribution: In hot-springs of Japan (Kobayashi 1957, p. 72; Yoneda 1941, p. 168; Emoto and Yoneda 1941, p. 10); in Western Indian spas (Thomas and Gonzalves 1963). Mainly distributed in tropical regions and commonly found in freshwaters.

References: Hustedt 1930, p. 358, fig. 660; Tiffany and Britton 1951, p. 279, pl. 74, fig. 862; Mizuno 1964, p. 164, pl. 61, fig. 862.

11. Genus **AMPHORA** Ehrenberg 1840

Cells united with concave valves into a long filamentous colony; cells sessile, broadly elliptical, with truncate poles; valves lunate; transverse striations; raphe gibbous; chromatophores single, two or four.

Key to Taiwan thermal species

- 1. Cell length more than 15 μ.....1. *A. Normani*
- 1. Cell length less than 10 μ.....2. *A. perpusilla*

**1. *Amphora Normani*** Rabenhorst

Cells 16-40×10-14 μ; lunate in girdle view with broadly rounded poles; intercalary bands numerous; valves lunate; central area absent; axial area narrow; central nodule large; transverse striations radial, 16-18 in 10 μ.

Taiwan: Wu-lai 40°C; Chin-shan 60°C; Jui-sui 35°C.

Distribution: Japanese hot-springs (Kobayashi 1957, p. 333, fig. E); Western Indian spas (Thomas and Gonzalves 1965); an aerial species growing with moss, and in freshwaters.

References: Hustedt 1930, p. 343, fig. 630; Tiffany and Britton 1951, p. 274 pl. 73, fig. 854; Kobayashi 1957, p. 333, fig. E; Mizuno 1964, p. 164, pl. 61 fig. 4; Skvortzov 1935, p. 185, pl. 1, fig. 30.

5. **Amphora perpusilla** Grunow

Cells  $405 \times 6-10 \mu$ , elliptical.

Taiwan: Chiao-shi  $54^{\circ}\text{C}$ .

Distribution: Common in freshwaters.

Reference: Hustedt 1930, p. 343, fig. 627.

12. Genus **RHOPALODIA** O. Müller 1895

Cells in girdle view more or less rectangular, band-like in shape, dorsally expanded and ventrally somewhat concave; transverse striations parallel.

Only one species was found in Taiwan spas.

**Rhopalodia gibberula** (Ehrenberg) O. Müller

Cells  $12-40 \times 25-80 \mu$ , a constriction at the middle of the dorsal part in girdle view, ventral part straight; poles somewhat inward curved.

Sample cells with distinct punctae and indistinct striations; poles protruded—these characteristics are different from the type; and so is thought of as a new kind.

Taiwan: An-tung  $58^{\circ}\text{C}$ ; Rua-shan  $35^{\circ}\text{C}$ .

Distribution: Common in salt waters and freshwaters.

In Japanese hot-springs (Mizuno 1964, p. 169, pl. 64, figs 4-6).

Reference: Hustedt 1930, p. 391, fig. 742.

11. Family 4 NITZSCHIACEAE

Two genera: Nitzschia and Denticula were found in Taiwan spas.

13. Genus **DENTICULA** Kützing 1844; emend. Grunow 1880

Cells free or joined valve to valve into a short chain; valves linear; lanceolate or elliptical, with scarcely brief keel; internal face of fissure with circular pores; punctae and costae; convex sides and truncate poles in girdle view.

Key to Taiwan thermal species

1. Cells less than  $10 \mu$  in length .....1. *D. thermalis*  
 1. Cells more than  $20 \mu$  in length .....2. *D. elegans*

1. **Denticula thermalis** Kützing

Cells  $5-7 \times 15-20 \mu$ .

Taiwan: Rua-shan  $35^{\circ}$ ,  $59^{\circ}$ ,  $89^{\circ}\text{C}$ .

Distribution: In Japanese spas (Emoto and Yoneda 1941); in St. Veit, Austria (Hustedt 1930, p. 382).

References: Hustedt 1930, p. 382, fig. 726; Emoto and Yoneda 1941, p. 11, fig. 5(5).

2. **Denticula elegans** Kützing

Cells  $5-7 \times 15-40 \mu$ .

The alga always accompanied with the former in the same cites, therefore both were considered as being one by many algologists (Emoto and Yoneda 1941, p. 11).

Taiwan: Rua-shan 35°, 44°, 59°, 89°C.

Distribution: An alpine species, on cliffs, in holes. In Japanese spas (Emoto and Yoneda 1941, p. 11)

Reference: Hustedt 1930, p. 382, fig. 725.

14. Genus **NITZSCHIA** Hassall 1845

Cells free or colonial; valve longitudinally asymmetric, straight, linear, sigmoid, elliptical, undulate, medially constricted or not, poles acute, rostrate, capitate, attenuate; one margin with a keel; cells elongate, rhombic or sigmoid in girdle view with attenuated poles; transverse striations or punctae; two chromatophores.

Key to Taiwan thermal species and varieties

- 1. Valve medially constricted .....2
- 1. Valve medially not constricted .....3
  - 2. Cell length more than 40  $\mu$ , with headed poles .....9. *N. parvula*
  - 2. Cell length less than 20  $\mu$ , without headed poles...5. *N. frustulum* var. *subsalsina*
- 3. Valves sigmoid .....9
- 3. Valves linear-lanceolate .....4
  - 4. Poles headed .....5
  - 4. Poles not headed, acute .....7
- 5. Keel distinct..... 3. *N. dissipata*
- 5. Keel indistinct or none .....6
  - 6. Cell length less than 15  $\mu$ , with linear margins .....6. *N. microcephala*
  - 6. Cell length more than 20  $\mu$ , with undulate or slightly medially constricted....  
..... 8. *N. palea*
- 7. Cell length less than 20  $\mu$  .....4. *N. frustulum* var. *perminuta*
- 7. Cell length more than 25  $\mu$  .....8
  - 8. Poles acute; keel with a raphe having small rectangular nodules .....  
.....2. *N. denticula*
  - 8. Poles obtuse; keel with a raphe having circular pores .....1. *N. amphibia*
- 9. Valve medially constricted .....9. *N. thermalis* var. *minor*
- 9. Valve polarly constricted .....7. *N. obtusa* var. *scalpelliformis*

1. **Nitzschia amphibia** (Kützing) Grunow

Cells 3-5×12-50  $\mu$ ; valve linear, with rounded, headed poles; distinct keel with pores; striation at one side of valve only, 15-10 in 10  $\mu$ .

Taiwan: Chin-shan 60°C.

Distribution: In Japanese hot-springs (Mizuno 1964, p. 177); common in freshwaters.

Reference: Hustedt 1930, p. 414, fig. 703; Mizuno 1964, p. 177, pl. 68, figs. 1-4.

**2. *Nitzschia denticula* Grunow**

Cells  $3-8 \times 10-100 \mu$ ; rectangular in girdle view, with straight sides and rounded poles; valves long-lanceolate, with acute poles; transverse striations 14-20 in  $10 \mu$ , keel punctae appearing costae, 5-8 in  $10 \mu$ .

Taiwan: Wu-lai 40°C; Chin-shan 60°C. Reduced forms were found at Wu-lai.

Distribution: Widely distributed but not common in freshwaters.

References: Hustedt 1930, p. 407, fig. 780; Tiffany and Britton 1951, p. 286, pl. 77, fig. 902.

**3. *Nitzschia dissipata* (Kützing) Grunow**

Cells  $4-7 \times 15-70 \mu$ ; long-lanceolate in girdle view, with small blunt poles; valves spindle-shaped with small rounded poles; striations invisible; keel punctae, 6-8 in  $10 \mu$ .

Taiwan: Chin-shan 60°C; Rua-shan 59°C.

Distribution: Common in freshwaters; in Japanese spas (Kobayashi 1957, p. 73).

References: Hustedt 1930, p. 412, fig. 789; Tiffany and Britton 1951, p. 288, pl. 76, fig. 898.

**4. *Nitzschia frustulum* var. *perminuta* Grunow**

Cells  $2-2.5 \times 11-17 \mu$ ; valve linear-lanceolate with obtuse poles; keel puncta 12-15 in  $10 \mu$ .

Taiwan: Chin-shan 60°C.

Distribution: Common in brackish waters.

Reference: Hustedt 1930, p. 415; Skvortzow 1935, p. 188, pl. 1, fig. 59.

**5. *Nitzschia frustulum* var. *subsalina* Hustedt**

Cells  $3 \times 20 \mu$ ; valve linear-lanceolate with acute poles; one side of margin medially constricted and the other smooth; keel puncta 15 in  $10 \mu$ ; striations scarcely visible.

Taiwan: Chin-shan 60°C.

Distribution: Common in brackish waters and in salty waters; in Japanese spas (Negoro 1942, p. 401)

References: Hustedt 1930, p. 415, fig. 796; Negoro 1942, p. 401, fig. 5 (3).

**6. *Nitzschia microcephala* Grunow**

Cells  $2.5-3.8 \times 11-12 \mu$ ; valves small with rostrate poles; keel puncta 11-15 in  $10 \mu$ ; striations 35 in  $10 \mu$ , but always invisible.

Taiwan: Chin-shan 60°C.

Distribution: Common in freshwaters; in Japanese spas (Kobayashi 1957, p. 236).

References: Hustedt 1930, p. 414, fig. 791; Skvortzow 1935, p. 189, pl. 1, fig. 64.

**7. *Nitzschia obtusa* var. *scalpelliformis* Grunow**

Cells  $6-9 \times 60-170 \mu$ ; valve broadly linear, with obliquely obtused poles; keel puncta 5-9 in  $10 \mu$ ; striations about 30 in  $10 \mu$ .



Taiwan: Chin-shan 60°C. Rare.

Distribution: in Japanese spas (Negoro 1942, p. 402; Kobayashi 1957, p. 73; Mizuno 1964, p. 176, pl. 67; in W. Indian hot-springs 28–69°C (Thomas and Gonzalves 1965, p. 26, 37); common in spas and brackish waters.

References: Hustedt 1930, p. 422, fig. 817b; Negoro 1942, p. 402, fig. 5 (2); Mizuno 1964, p. 176, pl. 67, figs. 13–15.

#### 8. *Nitzschia palea* (Kützing) W. Smith

Cells 2.5–6×20–65  $\mu$ ; valves linear-lanceolate with small protruded poles; striations 35–40 in 10  $\mu$ ; keel puncta 10–15 in 10  $\mu$ . Sample cells of two kinds: 6×38  $\mu$  and 3×24  $\mu$ ; their striations can scarcely be observed.

Taiwan: Wu-lai 40°C; Chiao-shi 45°C.

Distribution: in Japanese spas (Yoneda 1942, p. 99; Kobayashi 1957, p. 73; Mizuno 1964, p. 176, pl. 67); in copper-ion-riched waters especially growing in spas; also common in freshwater.

References: Hustedt 1930, p. 416, fig. 801; Tiffany and Britton 1951, p. 288 pl. 76, fig. 900; Mizuno 1964, p. 176, pl. 67, figs. 16, 17.

#### 9. *Nitzschia thermalis* var. *minor* Hilse

Cells 5–10×30–70  $\mu$ ; valve medially constricted, somewhat sigmoid, with small headed poles; striations 35 in 10  $\mu$ .

Sample cells 6–8×45  $\mu$ , striations scarcely visible.

Taiwan: Chin-shan 60°C.

Distribution: In Japanese spas (Yoneda 1941, p. 168); broadly distributed but not plentiful; found in highly concentrated waters.

References: Hustedt 1930, p. 403, fig. 772; Yoneda 1941, p. 168.

### Family SURIRELLACEAE

#### 15. Genus *SURIRELLA* Turpin 1828

Cells usually free, naviculoid, rectangular, cuneate or sigmoid in girdle view, girdles smooth; valves ovate, linear, elliptical; valve-faces bilaterally folded, with costae, keels having raphe, and pseudoraphe; chromatophore single.

Only one variety was found in Taiwan spas

#### *Surirella robusta* var. *splendida* (Ehrenberg) Van Heurck

Cells 40–60×75–250  $\mu$ ; valves ovate, not isopolar; costae 12–25 in 100  $\mu$ ; pseudo-  
raphe linear, narrow.

Taiwan: Wu-lai 52°C. (This plant was later found and added to the flora).

Distribution: Very common in freshwaters.

References: Hustedt 1930, p. 437, figs. 851, 852; Mizuno 1964, p. 179, pl. 69, figs. 8, 9.

## REFERENCES

- (1) EMOTO, Y. and Y. YONEDA., 1941, 42. Studies on the thermal-flora of Japan VIII, XVIII. Onsen Kagaku 1 (1, 2): 7-13, 5 figs; Acta Phytotax. Geobot. 11 (1) 7-26, 4 figs. (in Japanese)
- (2) HUSTEDT, F., 1930. Bacillariophyta (Diatomeae) in A. Pascher's, Die Susswasserflora Mitteleuropas. Heft 10, Jena.
- (3) KAFUKU, K., 1925. Mineral springs in Formosa. Transa. Nat. Hist. Soc. Formosa 15 (77): 47-54. (in Japanese)
- (4) KOBAYASHI, T., 1957. Diatom vegetation of Shiobara Spas; of Izu Katase, Yatsu and Yugoshima Spas. Bot. Mag (Tokyo) 70: 69-74; 232. (in Japanese)
- (5) MIZUNO, T., 1964. Illustrations of the freshwater plankton of Japan, pp. 351, 99 pls. Hoikusha, Japan. (in Japanese)
- (6) NEGORO, K., 1942. Die Diatomeenvegetation der Isobe-Mineralquellen. Bot. Mag. (Tokyo) 56: 401, 5 figs. (in Japanese)
- (7) SMITH, G. M., 1950. The freshwater algae of the United States (2nd ed.), pp. 440-510. McGraw-Hill.
- (8) SKVORTZOW, B. W., 1935. Diatoms from Calcutta, India. Philil. Journ. Sci. 58(2): 179-192, 1 pl.
- (9) ——— 1938a. Diatoms collected by Mr. Y. K. Okada in Nippon. I. Mountain bog diatoms flora from Prov. Sinano. Journ. Jap. Bot. 14 (3): 204-217, 3 figs.
- (10) ——— 1938b. Diatoms from the Philippines I. Diatoms from drinking water, Balara, Rizal Province. Philil. Journ. Sci. 64 (3) 287-298, 2 pls.
- (11) TIFFANY, J. E. and M. E. BRITTON., 1951. The algae of Illinois, pp. 214-296. Univ. Chicago Press.
- (12) THOMAS, J. and E. A. GONZALVES., 1965. Thermal algae of Western India. Hydrobiologia 25: 330-351; 26: 21-71.
- (13) YONEDA, Y., 1941. Studies on the thermal algae of Hokkaido (IV). Acta Phytotax. Geobot. 10 (3): 159-171, 6 figs. (in Japanese)
- (14) ——— 1942. Bacteria and algae of hot springs in Gihu Prefecture. Acta Phytotax. Geobot. 11 (2): 83-110, 4 figs. (in Japanese)