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A New Variety of *Cyclotella atomus* from Tokyo Bay, Japan; *C. atomus* var. *marina* var. nov.

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Abstract *Cyclotella atomus* var. *marina* var. nov., a small diatom that is abundant in nutrient-rich waters in Tokyo Bay (35°30′N, 139°50′E), is named and described. The new variety is a variety of *C. atomus* Hustedt, a cosmopolitan *Cyclotella* species that occurs mainly in fresh- to brackish-water (0–20 psu). Poorly developed costae are characteristic of the new variety. The new variety has no valve-face fultoportula, whereas *C. atomus* has one (and very occasionally two or nothing). The geographic variation in fluxes for the variety was calculated from sedimentation rates estimated from ^{210}Pb dates for 16 cores, in terms of valves/cm^2/year. The fluxes are high off the mouths of three major rivers flowing into the bay ($3.7–6.6\times10^7$ valves/cm^2/year), with a conspicuous decrease toward the middle of the bay ($0.1–1.5\times10^7$ valves/cm^2/year), suggesting the ecology of the new variety; it grows abundantly in waters of around 30 psu salinity, and is abundant in waters with higher nitrogen/phosphorus input from the catchment area of major rivers flowing into the northwestern part of the bay.

Key words : Tokyo Bay, Diatom, A new variety, *Cyclotella atomus* var. *marina*

Introduction

Over the past 60 years, large increases in nutrients resulting from human activities in the catchment area of rivers flowing into Tokyo Bay have caused significant changes in the phytoplankton ecology of the bay (*e.g.*, Yamaguchi, 1997). These changes are evidenced by a large increase in diatom production and a significant change in the diatom flora (*e.g.*, Brandini and Aruga, 1983).

In the course of our investigations of the flora from sediment cores, several diatom assemblages were found to be rich in a small diatom closely allied with *Cyclotella atomus* Hustedt (*Cyclotella* sp. c in Tanimura *et al.*, 2001, 2003).

Sediment cores from the bay and sediment and water samples from two rivers flowing into the bay provided material for observation of the diatom and for analyzing its modern distribution in the bay and rivers, which allowed us to infer the ecology of the diatom. Based on the studies, this paper describes the diatom as a new variety of *C. atomus*.

Materials and Methods

From August 7 to 15, 1981, a series of 32 sediment cores were collected from the bay during cruise G-81 of the Geological Survey of Japan. On November 13 and 22, 2002, two sediment samples were collected from the Tama River, and on June 23, 2003, one sediment sample and 9 water samples were collected from the Old Edo River. Of these, 7 sediment cores, 3 sediment samples and 9 water samples were used to observe the new variety and to determine whether the variety occurs mainly in marine water or occurs abundantly in fresh- to brackish-water (0–20 psu). For the determination, 200 valves of *Cyclotella* species were counted per sample at 1008–1600× under a LM (Table 1). A Zeiss Ax-

Table 1. Composition and abundances of *Cyclotella* species in the samples examined.

Cyclotella species/stations	Old Edo River										Tama R.		Tokyo Bay						
	51	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**	**61**	**62**	**2**	**7**	**8**	**11**	**14**	**20**	**26**
C. atomus	143	128	139	86	121	125	123	113	107	97	66	119	18	18	24	14	8	15	14
C. atomus var. *marina*	3	4	9	18	14	5	19	22	27	53	22	26	136	69	108	115	129	116	131
C. cryptica	5	8	2	25	8	14	9	5	12	9	54	18	1	9	2	6	2	1	4
C. medunae	4	10	12	5	19	3	1	11	6	10	1	1	7	5	4	6	2	6	4
C. meneghiniana	2	2	3	24	7	7	5	4	7	4	34	19	2	4	9	6	4	10	4
C. striata						1			2	1	1				3			4	2
C. pseudostelligera sensu lato	13	8	10	25	9	11	9	4	12	3	10	9		1	3	2	1		
C. caspia	5	6	1	3	8	1	6	2	5	3	1	2	1		10	2	4	6	3
Cyclotella sp. a						3		3			1		33	87	22	44	41	35	30
Other *Cyclotella* species	25	34	24	14	14	30	28	36	22	20	10	6	2	7	15	5	9	7	8
Total	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200

ioplan microscope equipped with differential interference contrast optics and a JEOL-5310 SEM were used for the counts, and a HITACHI 5500 FE-SEM and a JEOL 3300 TEM were used for observations on fine structure of the new variety.

For analyzing the variety's modern distribution in the surface sediments of the bay, the suspension in the near-bottom nepheloid layer (usually 1 to 3 cm thick) was sampled with a pipette immediately after each core recovery during the GSJ/G-81 cruise. These suspensions were fixed with 5% borate-buffered formalin and stored at 5°C. Absolute fluxes of the new variety were determined for 24 samples. For the determinations, quantitative splits of the sediments were filtered through 0.45 μm Millipore filters, rinsed with a small amount of distilled water, and dried. Each dried filter was mounted on a slide glass with immersion oil. The absolute fluxes were determined by scanning and counting a quantitative split of each filter at 1008× under a LM, with supplementary counts at 3,000–10,000× using a SEM.

^{210}Pb dates for 16 cores provided these cores' sedimentation rates (Matsumoto, 1983; Matsumoto, 1988). The sedimentation rates for eight cores without ^{210}Pb dating were determined by intercalation. Based on sedimentation rates, the geographic variation in fluxes of the new variety to the sea floor, was calculated in terms of valves/cm^2/year.

Observations

Cyclotella atomus var. *marina* Tanimura, Nagumo et Kato var. nov. (Figs. 3–15)

Cellulae solitariae, tympaniformia. Valvae circulares planae diametris 3–4.5 μm observatis, limbo leniter declivi. Spinis vel granulis in limbo valvae dispersis. Areolae in seriebus radialibus ordinatae, partim fasciculatae in margine, 2–8 striebus in quoque fasciculo. Costae marginales tenues. Fultoportulae marginales in omni tertio ad octavo costa, interne tubi cum duobus poris sateriticus. Rimoportula marginalis in costa singuralis, interne tubi brevi.

Cells solitary, dram-shaped. Valves circular

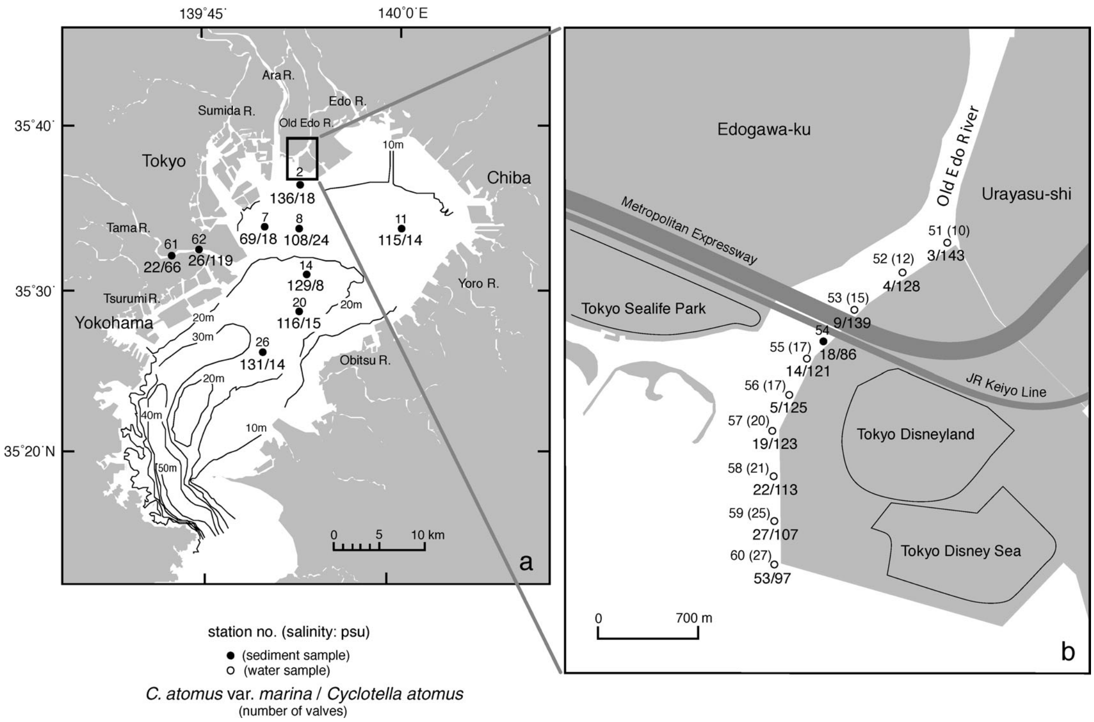


Fig. 1. Distribution of *Cyclotella atomus* Hustedt and *C. atomus* var. *marina* var. nov. in waters and surface sediments. Salinity (psu) for each water sample is given in a parenthesis (Fig. 1b).

with diameter of 3–4.5 μm observed. Valves flat with gently sloping mantle. Spines and granules scattered on the valve mantle. Areolae arranged in radiating rows, partly fasciculate in the marginal area, with 2–8 rows in each fascicle. Costae in the marginal area poorly developed. Fultoportulae occur in every 3rd to 5th costa, internally having a tube with two satellite pores. A single rimoportula on a costa with a short internal-tube.

Holotype: MPC-01776 (Micropaleontology Collection, the National Science Museum, Tokyo), Figs. 3a, b.

Type locality: Tokyo Bay.

Habitat: abundant in marine waters with a salinity optimum of around 30 psu.

Modern Distribution

The new variety appears to be distributed in waters of the Old Edo River in small numbers, never exceeding 14/121 in no. of *C. atomus* var. *marina* valves/no. of *C. atomus* valves ratio (station 55 in Fig. 1b), and a gradual increase in the abundance of the new variety can be observed from the mouth of the river toward the middle of the bay, reaching 129/8 in the ratio (station 14 in Fig. 1a). The new variety is common in sediments from the Tama River, up to 22/66 in the ratio (station 61 in Fig. 1a and Table 1).

Two area of maxima in fluxes of this variety occur in the bay (around stations 2, 7 and 13; about 3.7–6.6$\times 10^7$ valves/cm^2/year), and decrease toward the eastern and southeastern parts; 0.1–3$\times 10^7$ valves/cm^2/year (Fig. 2b).

Discussion

Specimens in about 80% of our material possess a marginal wall with alveoli composed of costae on which 3–5 fultoportulae and a rimoportula are located (Fig. 14). Therefore, we assigned them to the genus *Cyclotella*. The general valve morphology of this form is similar to that of *Cyclotella atomus* Hustedt.

Håkansson and Clarke (1997) clarified the

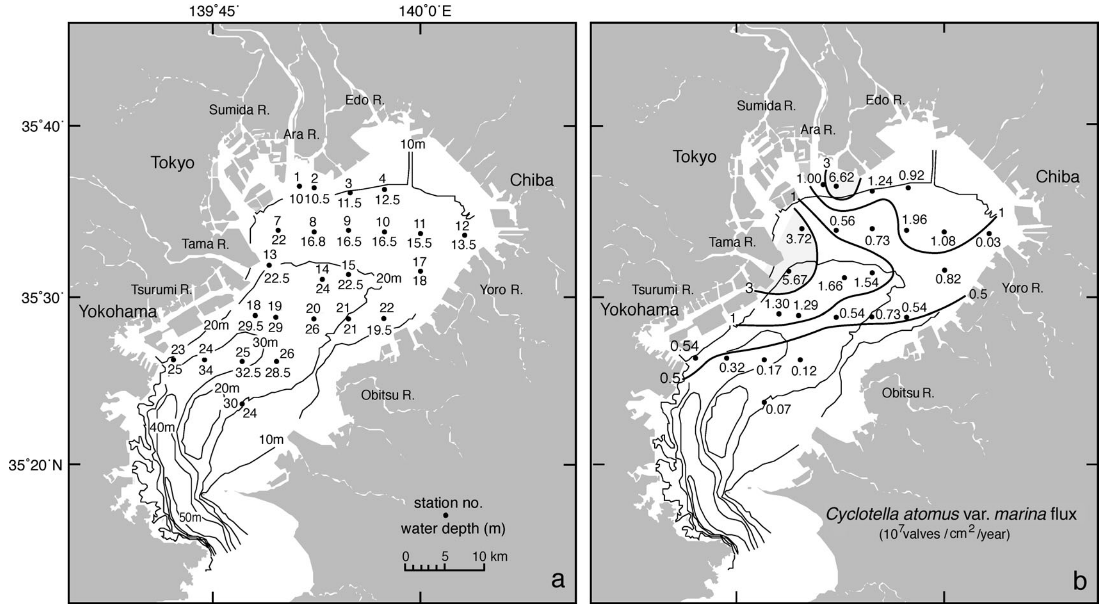
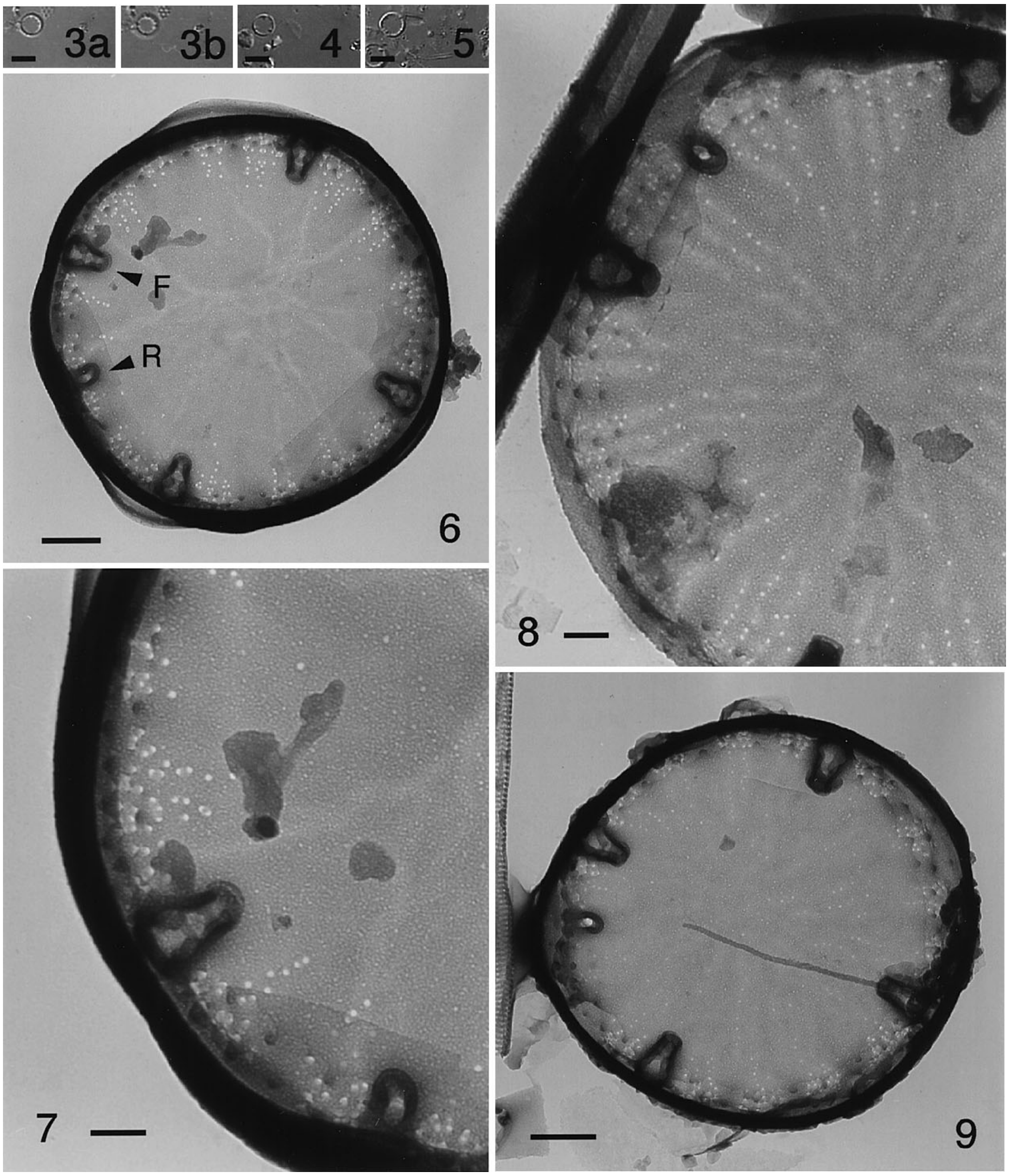


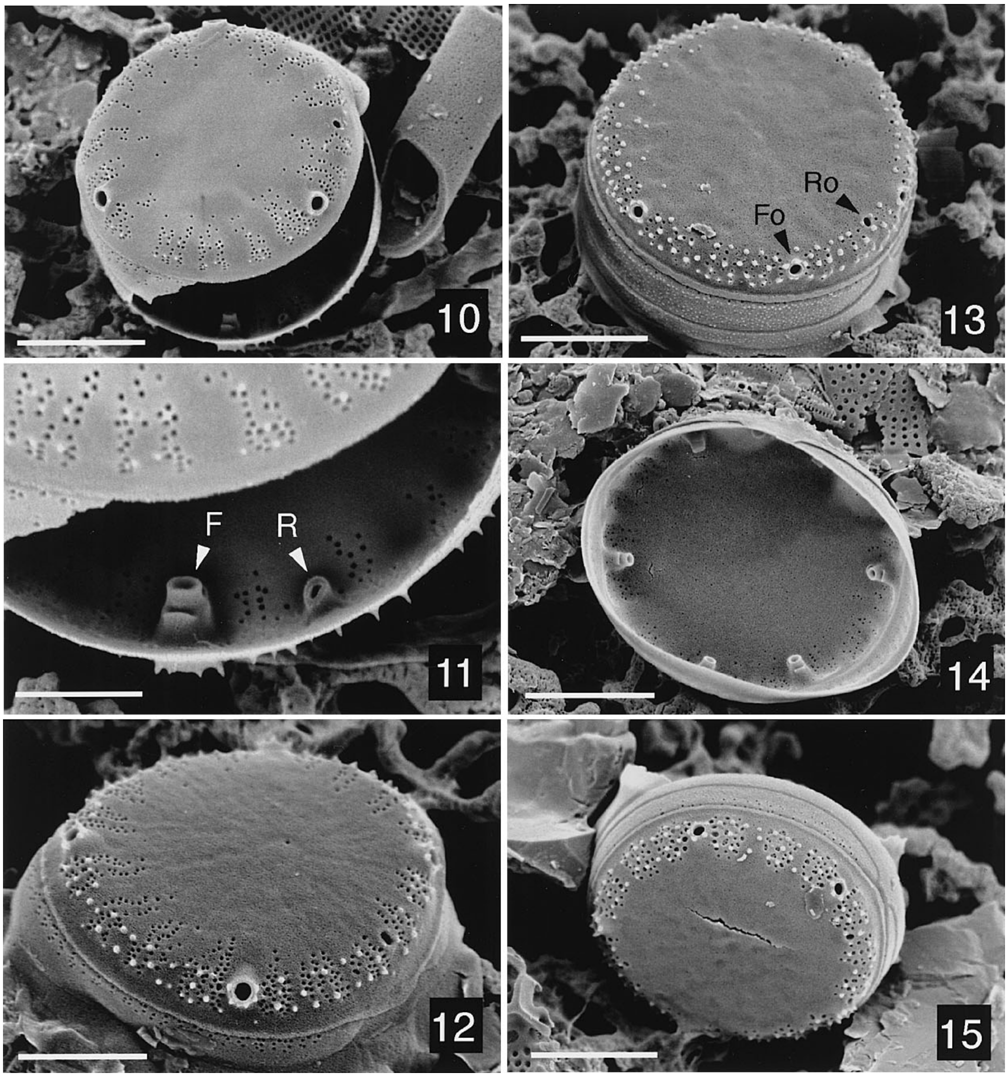
Fig. 2. Locations of 24 sediment-core samples used for flux determinations, and distribution of fluxes of *Cyclotella atomus* var. *marina* var. nov. Water depth (m) for each core is given under location number (Fig. 2a).

constant and variable-morphology of *C. atomus* valves from detailed LM and SEM observations of the type material and raw material from the type locality of *C. atomus* from Java (Hustedt collection). Namely, "the structure of the central area of the valve face, the number of valve-face fultoportulae, and the number of satellite pores of the mantle fultoportulae were constant, and valve shape and the number of satellite pores (2 or 3) on the valve-face fultoportula vary." They also stated that *C. atomus* has only one (very occasionally two) valve-face fultoportula. The new variety has a simple, nearly flat, central area and marginal fultoportulae with two satellite pores, which are common in both forms (Figs. 10, 12, 13). However, the new variety has no valve-face fultoportula (Figs. 3–10, 12–15). About 90 specimens observed by SEM lacked valve-face fultoportula. The new variety also differs from *C. atomus* in that it has poorly developed costae (Figs. 11, 14). Nagumo and Kobayashi (1985) showed some SEM and TEM images of *C. atomus* from the Japanese Islands. These included two specimens of *C. atomus* without valve-face fultoportula (plate 1, figs. 4, 9 in Nagumo and Kobayashi, 1985), but we could not determine whether the specimen shown in their fig. 9 was a morphotype of the new variety or belonged to *C. atomus*; the specimen has well developed costae and 9 marginal fultoportulae. The new variety also differs from a variety of *C. atomus*, *C. atomus* var. *gracilis* Genkal et Kiss (Genkal and Kiss, 1993), in that the new variety has no valve face fultoportula and poorly developed costae.

Håkansson and Clarke (1997) suggested that *C. atomus* is a fresh- to brackish-water species (0–20 psu), while the new variety occurs mainly in marine waters. Our investigation revealed that the new variety is rare to common in river waters (10–17 psu) and is most abundant in two areas, both located off the mouths of large rivers (Figs. 1 and 2). The salinity in these two areas ranges from 25 to 32 psu at the surface and 30–34 psu at a depth of 50 m, suggesting that the new variety grows abundantly in waters with a salinity of around 30 psu (salinity data; http://www.awa.or.jp/home/cbsuishi/04tokyowan.html).



Figs. 3–9. *Cyclotella atomus* var. *marina* var. nov., LM and TEM. 3a, b. Holotype (MPC-01776, Micropaleontology Collection, the National Science Museum, Tokyo), LM, station 2, scale bars $=5\,\mu$m. 4. A specimen with three marginal fultoportulae, LM, station 2, scale bars $=5\,\mu$m. 5. A specimen with four marginal fultoportulae, LM, station 2, scale bars $=5\,\mu$m. 6 and 7. A specimen with areolae partly in clusters on the valve mantle, TEM, F; fultoportula, R; rimoportula, station 2, scale bars $=0.5\,\mu$m (Fig. 6) and $0.2\,\mu$m (Fig. 7). 8. A specimen with radial areolae rows, TEM, station 2, scale bar $=0.2\,\mu$m. 9. A specimen with areolae partly in clusters on the valve mantle, TEM, station 2, scale bar $=0.5\,\mu$m.



Figs. 10–15 *Cyclotella atomus* var. *marina* var. nov., SEM. 10. A broken frustule, station 2, scale bar=1.5 μm. 11. Internal view of a valve, showing a fultoportula with two satellite pores (F) and a rimoportula (R), station 2, scale bar=0.6 μm. 12. A whole valve with radial areolae rows, station 2, scale bar=1.0 μm. 13. An intact frustule with external openings of fultoportulae (Fo) and rimoportula (Ro), station 2, scale bar=1.5 μm. 14. Internal view of a whole valve, showing poorly developed costae, some with fultoportulae and a rimoportula, station 2, scale bar=1.5 μm. 15. An intact valve with areolae in clusters on the valve mantle, station 2, scale bar=1.5 μm.

The new variety is abundant in the northwestern part of the bay, where a nutrient-rich water mass prevails year-round, owing to the nutrients supplied from three major rivers: the Tama, Sumida, and Ara. In 1989, 319.4 t/day of nitrogen and 25.98 t/day of phosphorus were supplied to the bay, of which 250.1 t/day of the former and 20.3 t/day of the latter came from river discharge (Ogura, 1993; cited in Furota, 1997, Table 1). Therefore, about 78% of the total nitrogen/phosphorus input is from river discharge. Hence, we also suggest that the new variety grows in nutrient-rich waters. Along with this ecological evidence, the close morphological similarity between the new variety and *C. atomus* led us to infer that the new variety differentiated from *C. atomus* following its invasion of marine water from fresh/brackish water.

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