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Observations on a rare planktonic dinoflagellate, *Dinofurcula* cf. *ultima* (Dinophyceae), from the Mexican Pacific

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The genus *Dinofurcula* was erected by Kofoid & Skogsberg (1928), based on *Phalacroma ultima*, described in 1907. The genus and its two species (*D. ultima* and *D. ventralis)* have not been reported in the literature since their first description and renaming. Here we provide morphological information obtained by light and scanning electron microscopy on *D.* cf. *ultima*, recorded in the tropical Mexican Pacific. The cells have a 'molariform body', due to the presence of two large posterior processes; the dorsal-posterior one is triangular and acute, and different from the 'horn' originally described. A short crest runs on the left epithecal plate parallel to the suture band of the epitheca. The sulcus is located laterally, displaced toward the right side of the hypotheca. The theca is scattered with areolae and pores, but they are less dense on or absent from the ventral-posterior process and on the dorsal margin of the dorsal-posterior one. Specimens found in this study are smaller (31–36.5 μm in length) than those described originally. *Dinofurcula ultima* may be regarded as a tropical form distributed in tropical and subequatorial waters of the Pacific Ocean.

INTRODUCTION

Dinoflagellates are a diverse and complex group of unicellular flagellates that constitute a very important and often abundant component of the marine phytoplankton. In the Mexican Pacific Ocean, most studies on dinoflagellates have been dedicated to floristic and taxonomic aspects (Osorio-Tafall 1942; Graham 1943; Hernández-Becerril 1985, 1988a, b, c, 1989, 1991, 1992; Licea *et al.* 1995; Hernández-Becerril *et al.* 2000, 2003), but there are several regions where these investigations have never been carried out, especially in the so-called tropical Mexican Pacific.

During the analysis of phytoplankton samples collected during an oceanographic cruise carried out in the Gulf of Tehuantepec (tropical Mexican Pacific Ocean), we found *Dinofurcula* cf. *ultima* (Kofoid) Kofoid & Skogsberg, which is a new record for Mexican waters.

The genus *Dinofurcula* Kofoid & Skogsberg was erected in 1928 (Kofoid & Skogsberg 1928), based on *Phalacroma ultima* Kofoid (Kofoid 1907). The genus and its two species, *D. ultima* and *D. ventralis* Kofoid & Skogsberg, were originally found in tropical waters of the Pacific Ocean (eastern tropical Pacific) as extremely rare, and have not been reported since their first description. The genus has been placed within the Order Dinophysiales (Kofoid & Skogsberg 1928; Schiller 1933; Sournia 1986; Fensome *et al.* 1993) because it shows similarities with *Dinophysis* Ehrenberg or *Phalacroma* Stein. Species within the Order Dinophysiales are characterized by motile, mostly planktonic, solitary cells of small to medium size (most species range between 30 and 120 μm in length). Cells are laterally compressed and have a larger hypotheca, consisting of two large hypothecal plates united by a sagittal suture, and a reduced epitheca (Norris & Berner 1970; Steidinger & Tangen 1997).

This paper presents new observations on the morphology and distribution of *D.* cf. *ultima*, a rare species of tropical affinity, for which the only iconographic information available is represented by the original drawings (Kofoid 1907; Kofoid & Skogsberg 1928). We provide further information obtained by light and scanning electron microscopy (LM and SEM, respectively) and comment on the taxonomy of the species and the genus.

MATERIAL AND METHODS

Observations are based on field samples collected on the R/V El Puma, during a cruise (PACMEX III, 6–17 April 2000) in the Gulf of Tehuantepec, Mexican Pacific Ocean (Fig. 1). This area is a very rich and productive system, where wind-forced upwellings play an important role in maintaining high productivity (e.g. Gallegos García & Barberán Falcón 1998).

Bottle samples (4 litres) were taken regularly at 5, 25 and 50 m (samples from 10, 30 and 40 m were occasionally collected) from 41 stations. Samples were filtered through Millipore polycarbonate filters (Millipore, Mexico City, Mexico) of 0.45 μm pore size and washed with 30 ml of distilled water (with no fixatives added). Additionally, net samples (64 μm mesh) were taken from the same stations, in vertical (50–100 m depth) hauls, and fixed with formalin (4%). Temperature, salinity and dissolved oxygen concentrations were measured at all stations.

Filters were mounted on a slide and examined in LM, using immersion oil to clear the filters (Bollmann *et al.* 2002). Observations by SEM were also made. A small piece of each filter (about 1 cm^2) was mounted on a stub, dried and coated with gold; critical point drying was not used. A Zeiss Axiolab

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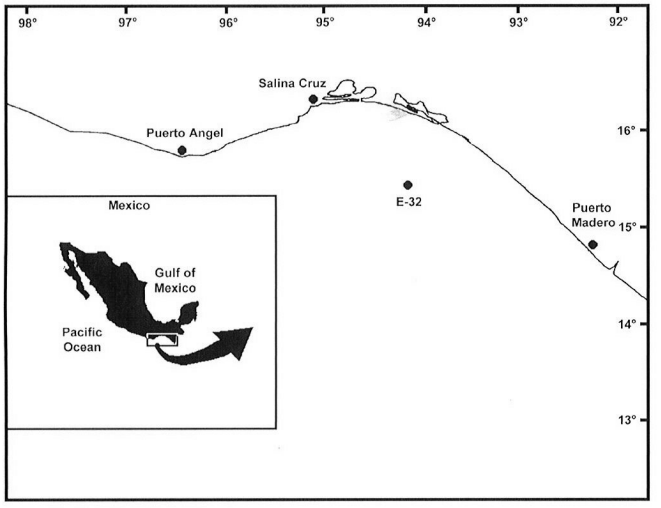

Fig. 1. Map of the study area, showing location of the station in the Gulf of Tehuantepec, Mexico, where specimens of *Dinofurcula* cf. *ultima* were found.

light microscope using bright field and phase contrast optics (Carl Zeiss de Mexico, Mexico City, Mexico) and a JEOL 1200 EX scanning electron microscope (JEOL de Mexico, Mexico City, Mexico) were used for our observations.

RESULTS

Order Dinophysiales Kofoid

Family Dinophysiaceae Stein

Genus *Dinofurcula* Kofoid & Skogsberg

SYNONYM: *Phalacroma* Stein *partim* (Kofoid & Skogsberg 1928).

Dinofurcula cf. *ultima* (Kofoid) Kofoid & Skogsberg

Figs 2–7

ORIGINAL REFERENCE: Kofoid & Skogsberg (1928, p. 203, fig. 28: 1, pl. 5, figs 4, 6).

OTHER REFERENCES THAT REPRODUCE ORIGINAL DRAWINGS AND INFORMATION: Schiller (1933, p. 107, figs 99a, b); Larsen & Sournia (1991, p. 318, fig. 21.9).

SYNONYM: *Phalacroma ultima* Kofoid (1907, p. 195, pl. 12, fig. 68).

Cells are 31–36.5 μm long and 25.4–29 μm wide (n = 7 cells), strongly compressed laterally. The epitheca is reduced, the hypotheca elongated; cingular and sulcal lists are poorly developed. The most conspicuous and characteristic features are the lateral position of the sulcus (in right lateral view) and the bifurcation of the hypotheca, showing two posterior processes. Kofoid & Skogsberg (1928) used the term 'molariform body' to describe the general shape of the cells (Figs 2–4).

The epitheca is low and dome-shaped (8–10.5 μm in height) and it protrudes over the anterior cingular list (Figs 2, 4). A short list or crest is present on the left epithecal plate (E2) and runs parallel to the suture line of the epitheca, directed toward the ventral side (Figs 2, 4, 5, 7). In one specimen, a short spine-like process was observed rising from the suture line, in front of this crest (Fig. 5). A furrow is formed between the crest and the suture of the epitheca (Figs 5, 7).

The cingulum is wide and excavated (4.5–7 μm wide), with a list at both the anterior and posterior edge (width of cingular lists 3.5–5 μm), each with numerous ribs (Figs 2–4); both lists are wider at the sagittal suture line, especially on the ventral part (Figs 4, 5). The anterior cingular list is descending; the posterior cingular list is continuous with the left sulcal list, which develops on the right theca (hypothecal plate, H_2) of the cells (Figs 3, 6). The sulcus is only visible in right lateral view as a characteristic longitudinal furrow to the right of the hypothecal plate, and it extends between the two posterior processes of the hypotheca (Fig. 3). The right sulcal list has a number of ribs (Fig. 3). The sulcus is 3.5–5.5 μm wide, with lists between 2.6 and 3.8 μm wide.

The hypotheca is bifurcated, bearing two posterior processes. The ventral margin of the hypotheca, just below the cingulum, is strongly curved. The ventral-posterior process is horn-like, straight and slightly tapering distally, and forms an angle of about 45–50° with the dorsal-posterior process (Figs 2–4). The maximum separation between the two tips of the posterior processes ranges between 14 and 18 μm. The dorsal-posterior process is larger than the ventral-posterior one, has a triangular shape and becomes acute at its end (Figs 2–4). The dorsal margin of the hypotheca may be straight or smoothly curved, mainly just below the cingulum (Figs 2–4).

Small pores are distributed throughout the theca (Figs 2–5). However, no areolae or pores are present on the antapical part of the ventral-posterior process or on the dorsal margins of the dorsal-posterior process (Figs 2, 3, 7). Areolae may have one or no pores (Fig. 5); a row of pores runs along the epithecal and hypothecal plates close to the cingular lists (Fig. 5). Areolae are not very deep in most specimens, but one specimen showed deeper areolation. No observations were made on the presence of chloroplasts in the cells examined.

Seven specimens of *D.* cf. *ultima* were found in only one sample collected at a depth of 30 m at Station 32 (location: 15°17′N, 94°14′W). The examination of net samples did not provide further records of the species.

The temperature of the water column (0–30 m) ranged between 23.4°C (surface) and 14.6°C (30 m), and the thermocline was located at about 20 m. Salinity values ranged between 34.4 and 34.7 psu, at 10 and 30 m, respectively. The

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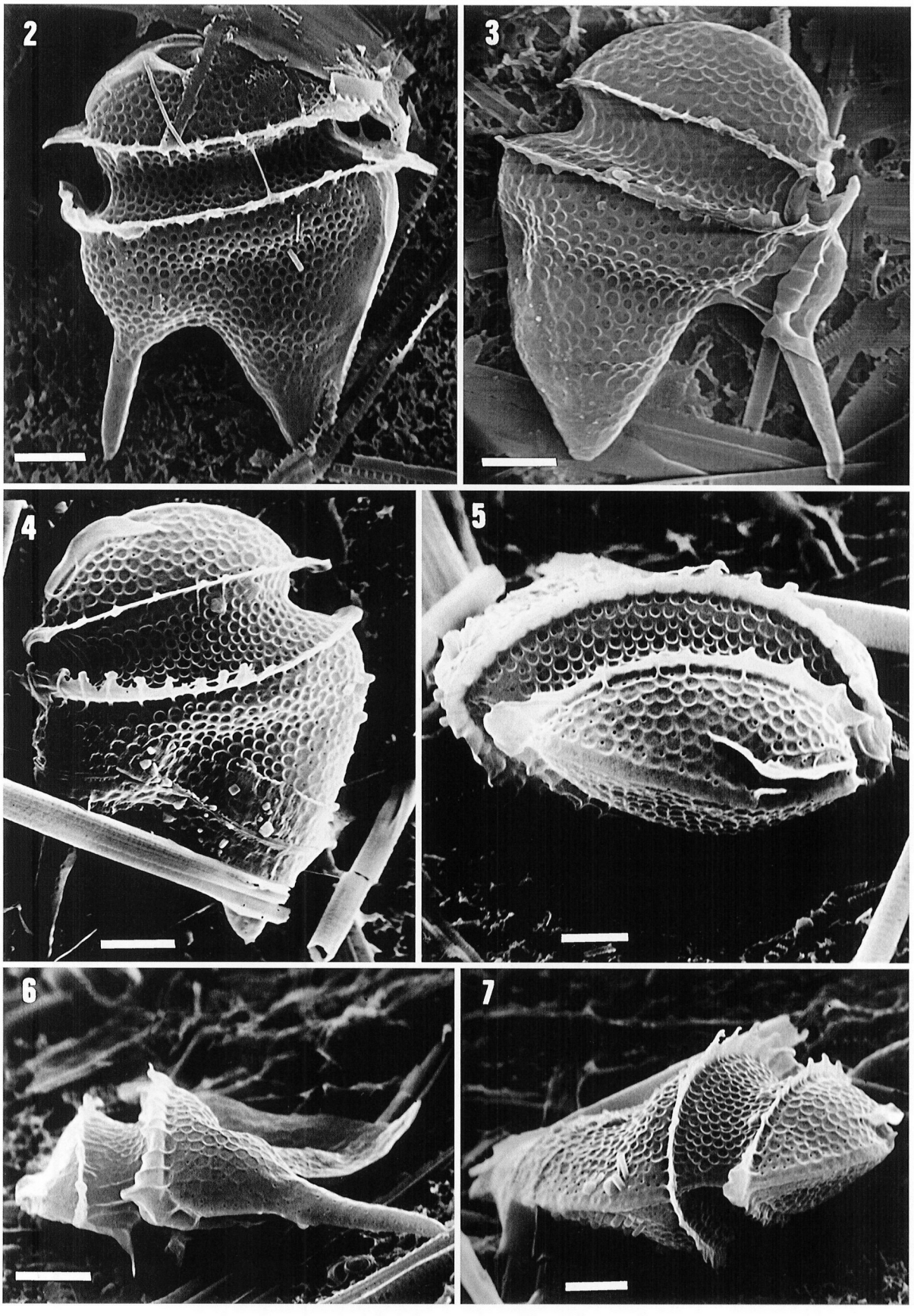
Figs 2–7. *Dinofurcula* cf. *ultima*, SEM. Scale bars = 5 μm.
Fig. 2. Cell in left lateral view, showing a wide and excavated cingulum and a crest in the epitheca.
Fig. 3. Another cell in right lateral view, showing the sulcal lists and the sulcus.
Fig. 4. Another cell in left lateral view, showing a crest in the epitheca.
Fig. 5. Apical view of a cell, showing details of the epitheca and the crest.
Fig. 6. Cell in ventral view, with details of the cingular lists (the posterior one forming the left sulcal list) and the posterior processes.
Fig. 7. A specimen in dorsal view, exhibiting a furrow in the epitheca, next to the crest.



phytoplanktonic community associated with *D.* cf. *ultima* consisted largely of the pennate diatom *Lioloma* Hasle, together with several species of the centric diatom genus *Thalassiosira* Cleve and a few thecate dinoflagellates and coccolithophorids.

DISCUSSION

Three morphological characters found in specimens recorded in the tropical Mexican Pacific Ocean were different from those described for *D. ultima* (Kofoid 1907; Kofoid & Skogsberg 1928). Specimens of the original description had a more pointed dorsal-posterior process that looked like a 'horn' and was more similar to the ventral-posterior one. The top of the epitheca was more domed in the original description and the cell dimensions were nearly double those of the specimens illustrated here. Therefore, we have decided to name our specimens *D.* cf. *ultima.*

The general outline of *D. ultima* is one of the most characteristic morphological features of the species and genus. The 'molariform body' is unique among the Dinophysiales, although other genera and species have a so-called 'tripartite' morphology, for example the genus *Triposolenia* Kofoid (Kofoid 1906a, b; Hernández-Becerril & Meave 1999), whereas some species of *Amphisolenia* Stein show bi-, tri-, tetra- or pentafurcated posterior processes (e.g. Schiller 1933).

The lateral position of the sulcus to the right of the hypotheca in *D. ultima* is also a prominent morphological character. Only one other species in the Family Dinophysiaceae, *Metaphalacroma skogsbergi* Tai *in* Tai & Skogsberg (Tai & Skogsberg 1934; Balech 1988), shows some degree of displacement of the sulcus to the right.

The second species of *Dinofurcula, D. ventralis,* was separated from *D. ultima* because of the presence of a straight sulcus, although outline and size are very similar in the two species. Species of the genus *Sinophysis* Nie & Wang, traditionally considered members of the Order Dinophysiales, but occurring in benthic habitats, have a displaced sulcus that is also located in the right hypotheca and is as long as two thirds of the length of the cells (Hernández-Becerril 1988b; Faust 1993; Hoppenrath 2000); however, all other morphological characters of the genus *Sinophysis* differ from those of *Dinofurcula.*

Another character peculiar to *D. ultima* is the presence of a crest on the epitheca. The presence of this crest is clearly indicated in the original description, where the epitheca shows a 'bump' toward the ventral end. This feature is, however, slightly less conspicuous in other species of the Dinophysiales, for example *Metaphalacroma skogsbergi* and *Pseudophalacroma nasutum* (Stein) Jörgensen (e.g. Balech 1988; Hernández-Becerril 1988a).

Very little morphological variation was detected in the specimens of *D.* cf. *ultima* studied here, although the shape of the dorsal-posterior process varied slightly. Specimens found in this study were considerably smaller than those reported in the original description. Smaller cells with slightly different morphology might be interpreted as a different stage within the species life cycle, as has been reported for species of the genus *Dinophysis* (Reguera & González-Gil 2001), or they might represent different developmental stages of the cells through their lifetime (Hallegraeff & Lucas 1988).

The genus *Dinofurcula* and its two species were originally found in tropical and subequatorial waters of the Pacific Ocean (Peruvian Current, following Kofoid & Skogsberg 1928); thus they are regarded as tropical forms. Our finding in the Gulf of Tehuantepec supports this distribution. This is the first report of a species of the genus *Dinofurcula,* after the original description and subsequent renaming, and it is the first record in Mexican waters, in both the Atlantic and Pacific Oceans. A recent survey of phytoplankton in the Gulf of Tehuantepec (Meave & Hernández-Becerril 1998) did not report the presence of this genus, and a more recent revision of the Order Dinophysiales in Mexican waters does not include any record (Hernández-Becerril *et al.* 2003). The recognition of the genus and the species is relatively easy, so researchers are unlikely to get confused or ignore their presence.

Our observations indicate that *D.* cf. *ultima* might prefer subsurface layers (30 m); Kofoid & Skogsberg (1928) claimed that the genus *Dinofurcula* 'has not been found as yet in the surface waters'.

The genus *Dinofurcula* and, at least, *D. ultima,* are reported to be heterotrophic (Larsen & Sournia 1991). We were unable to detect chloroplasts in *D.* cf. *ultima.*

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