Characterization of a magnetotactic bacteria-grazing ciliate in sediment from the intertidal zone of Huiquan Bay, China

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INTRODUCTION

Magnetotactic bacteria (MTB) represent a group of microorganisms with the ability to orient and swim along geomagnetic field lines. They can synthesize magnetosomes through the biomineralization process. Previously studies have reported that some species of protozoa can graze MTB and accumulate magnetosomes in the cells. Here, we characterize a slightly magnetically responsive MTB-grazing ciliate from the intertidal sediment of Huiquan Bay.

RESULTS

The discovery of magnetically responsive ciliates

In the same intertidal sediment sample, both magnetotactic bacteria and magnetically responsive protists were observed (Fig.1) The protozoan was identified as ciliate under light microscope.

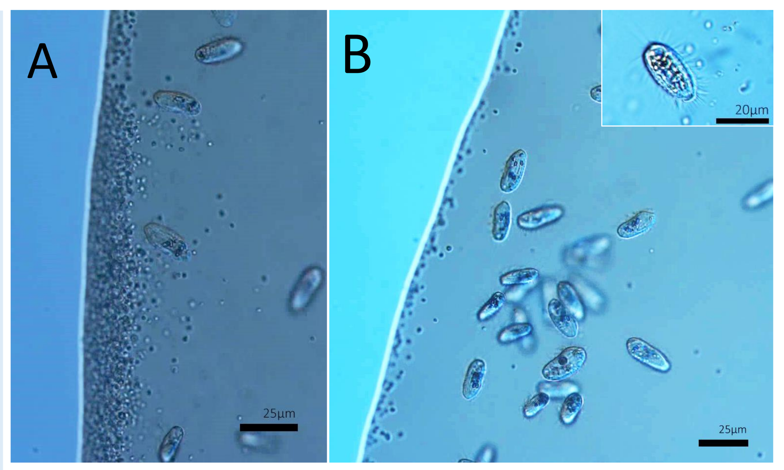

FIGURE.1 A, B: Light microscope images of ciliates and magnetotactic bacteria sampled in the Huiquan Bay, China. Ciliate cells are ~20 μm long, 12 μm wide.

Morphology of MTB, ciliates and magnetosomes

Different shapes of MTB were found under transmission electron microscopy. Magnetotactic cocci are dominant. Five different shapes of magnetosomes were observed in MTB. Magnetosomes in magnetotactic cocci were arranged in single or multiple chains or irregularly. Magnetosomes in vibrio and spiral MTB were just arranged in a single chain. The size of magnetosomes in magnetotactic cocci was larger than that in vibrio and spiral MTB (Fig.2, 3).

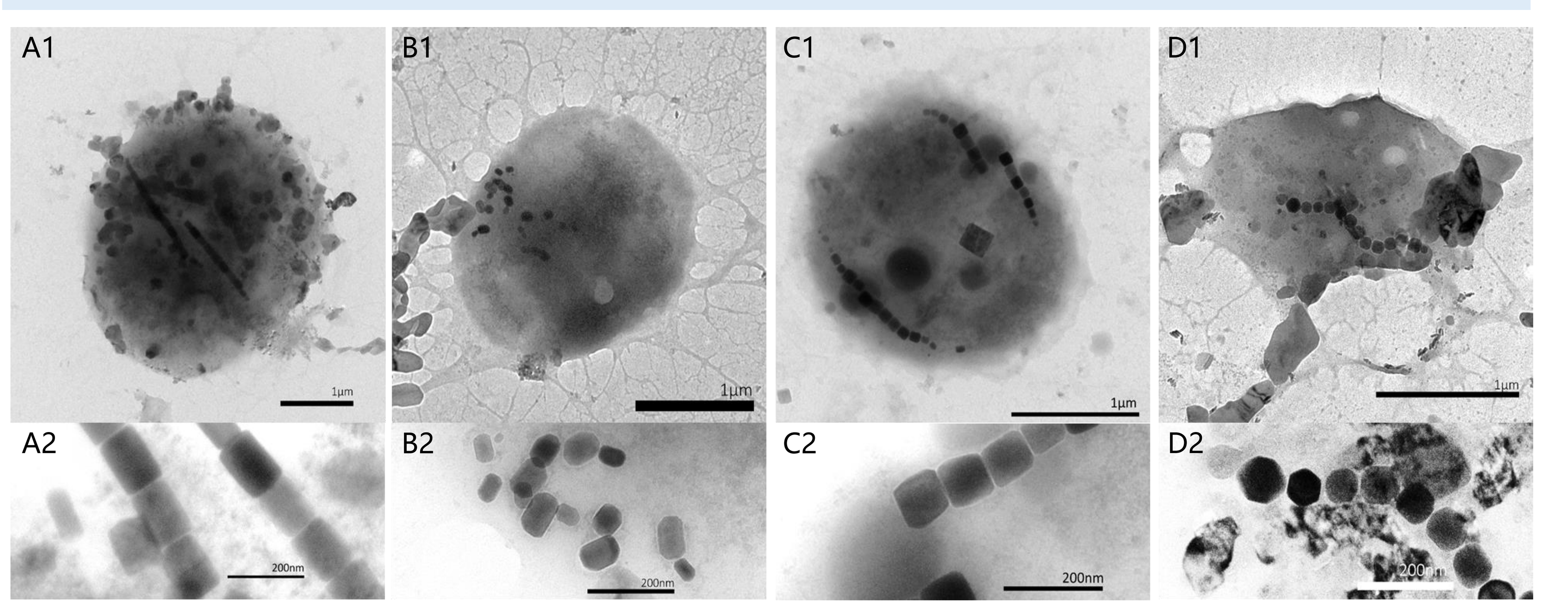

FIGURE.2 Transmission electron microscopy images of magnetotactic cocci sampled in the Huiquan Bay, China. A1, B1, C1, D1: magnetotactic cocci A2: elongated hexagonal prism shape magnetosome (~130 nm long, 92 nm wide. n=69, c=7). B2: hexagonal prism shape magnetosomes (~81 nm long, 53 nm wide. n=580, c=34). C2: prismoid shape magnetosome (~82 nm long, 79 nm wide. n=69, c=3). D2: cuboctahedron shape magnetosome (~ 80 nm long, 75nm wide. n=13, c=1). n: number, c: cell

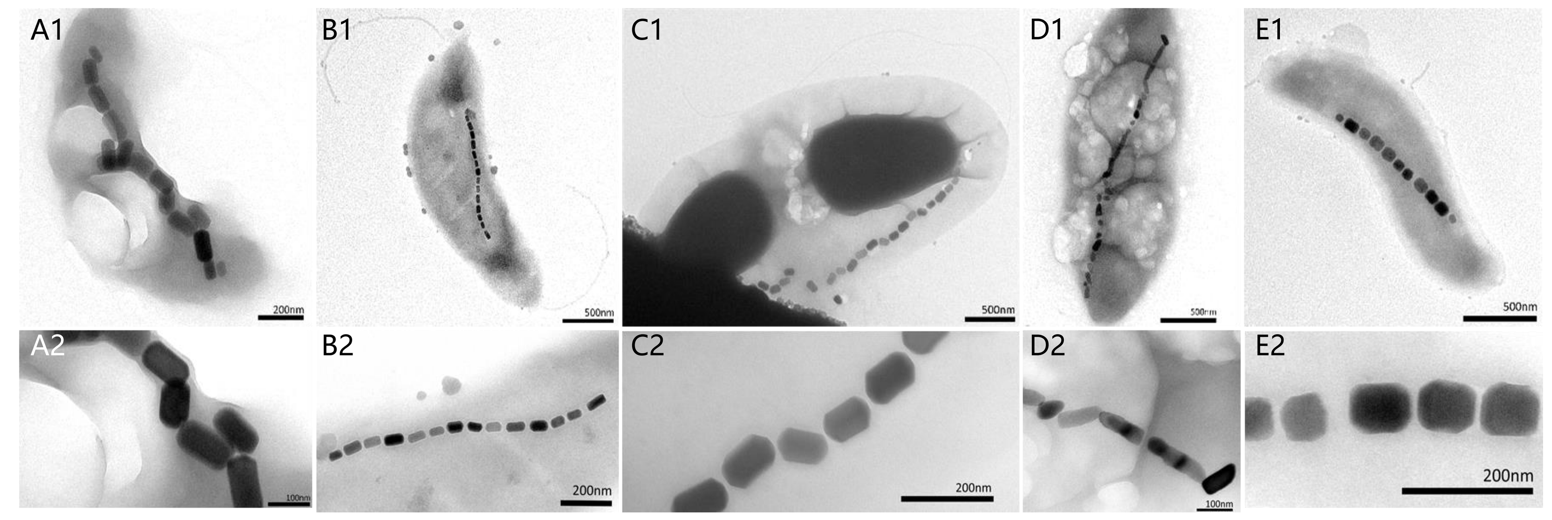

FIGURE.3 Transmission electron microscopy images of vibrio and spiral MTB sampled in the Huiquan Bay, China. A1, B1, C1, D1: Vibrio MTB. E1: Spiral MTB. A2, B2, C2, E2: elongated hexagonal prism shape magnetosome (~ 90 nm long, 55 nm wide. n=361, c=21). D2: bullet-shaped magnetosome (~ 105 nm long, 49nm wide. n=46, c=3). n: number, c: cell

Using transmission electron microscopy, we observed that two to four different shapes of magnetosomes were randomly distributed within this ciliate. Magnetosomes of different shapes in magnetotactic cocci were larger than that in ciliates (Fig. 2, 4). Bullet-shape magnetosomes both observed in MTB (Fig.3) and ciliate.

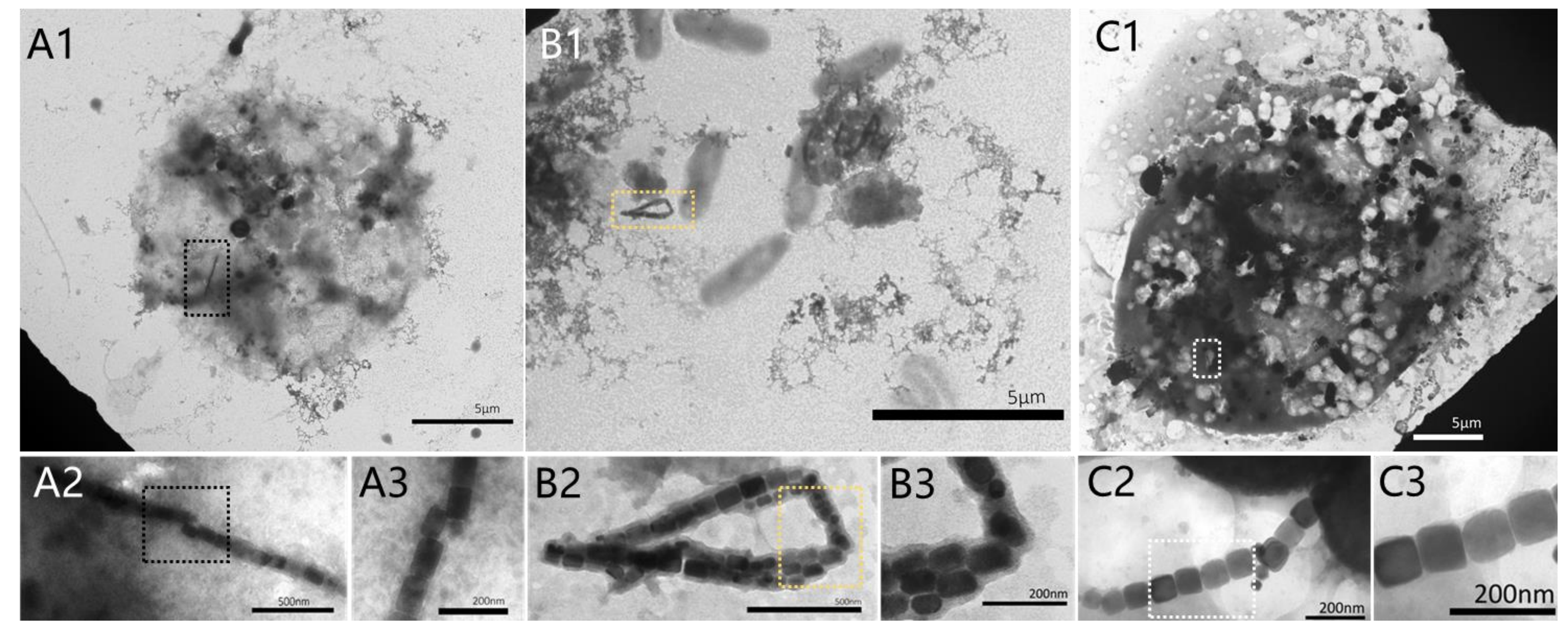

FIGURE.4 Transmission electron microscopy images of magnetically responsive ciliates sampled in the Huiquan Bay, China. A1, B1, C1: ciliates. A2, A3: elongated hexagonal prism shape magnetosomes (~ 95 nm long, 67 nm wide. c=9, n=168). B2, B3: hexagonal prism shape magnetosomes (~ 80 nm long, 53 nm wide. c=9, n=168). C2, C3: prismoid shape magnetosome (~81 nm long, 77 nm wide. n=10, c=1). n: number, c: cell

Components of magnetosomes in ciliates

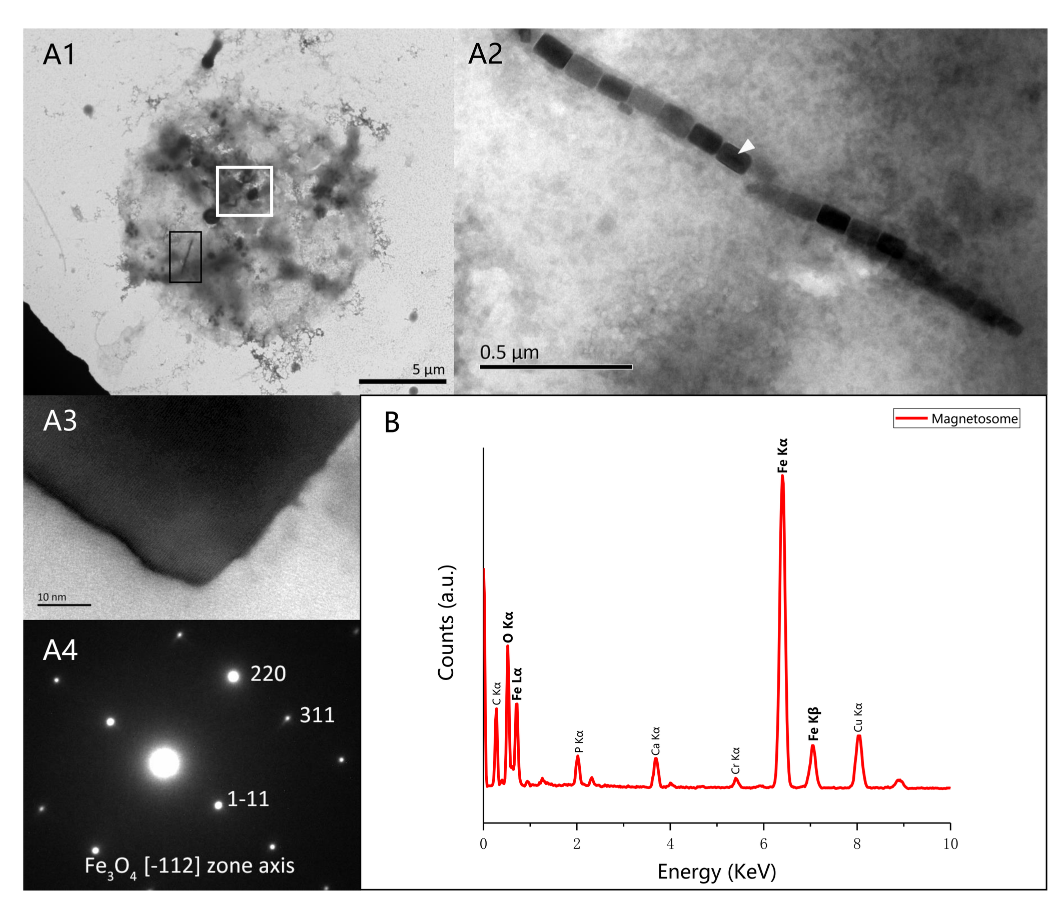

FIGURE.5 Characteristics of the elongated hexagonal prism shape magnetosomes of ciliate.
A1: Ciliate cell with different shapes intracellular magnetosomes.
A2: enlargement of the black square area of A1, showing elongated hexagonal prism shape magnetosomes.
A3: High-resolution TEM image of a single magnetosome biomineralized (The white arrow points to the position of A2).
A4: Electron diffraction pattern of A3.
B: Energy dispersive X-ray (EDX) analysis of magnetosomes (A3).

Energy-dispersive X-ray spectroscopy and high-resolution transmission electron microscopy images of magnetosomes were consistent with magnetite(Fig.5). The same components of magnetosomes were both detected in MTB and ciliates occurred in the same environment.

Phylogenetic analysis

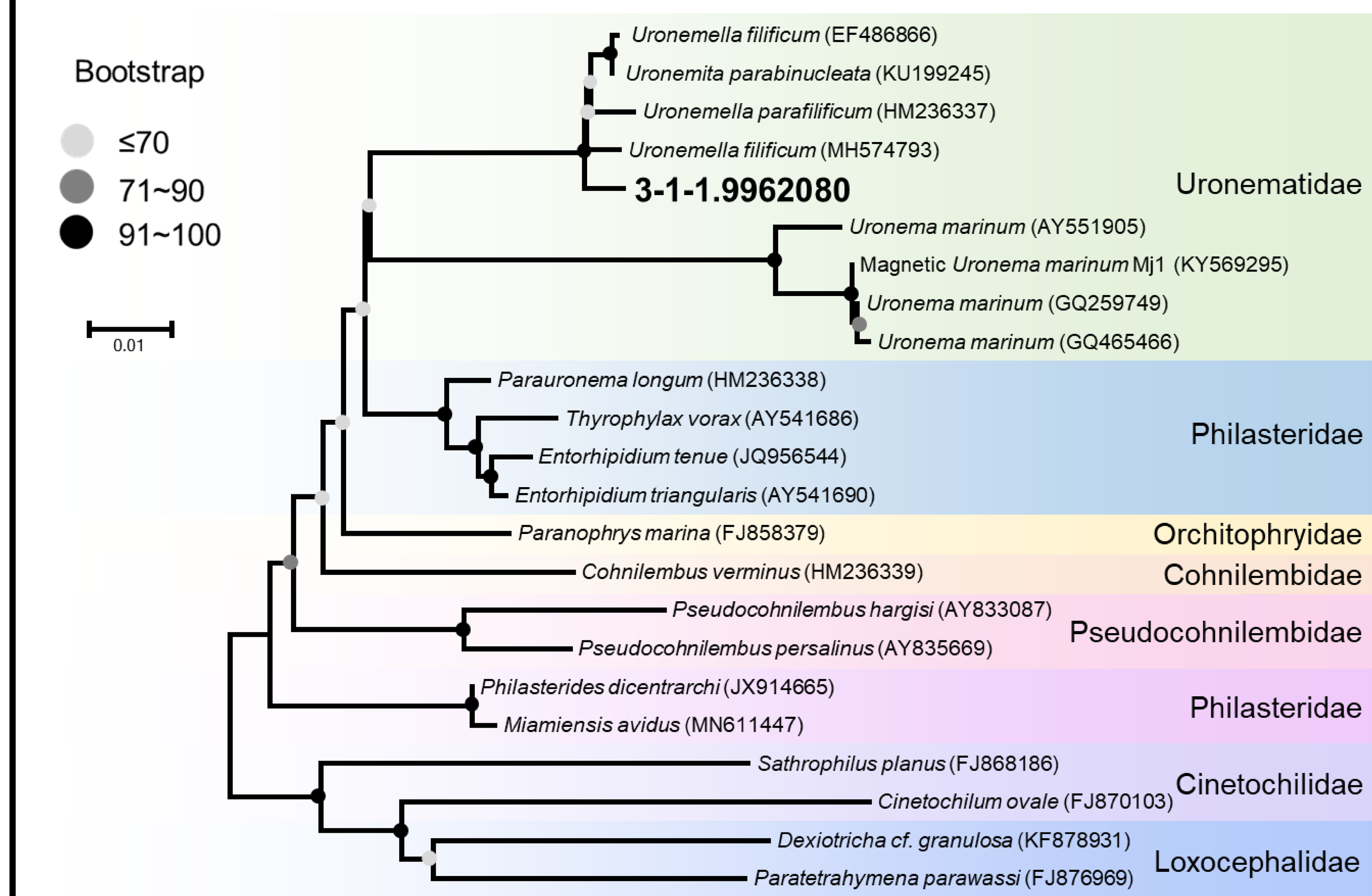

FIGURE.6 Neighbor-joining tree for 3-1-1.9962080 based on 18S rRNA gene sequences. The sequence determined in this study is shown in bold text. GenBank accession numbers of the sequences used are indicated in parentheses.

The 18S rRNA gene sequence of the magnetic ciliate showed 99.09% identities with that of *Uronemella parafilificum*. Phylogenetic analysis showed 3-1-1.9962080 is affiliated to Uronematidae (Fig.6). Monteil et al reported a ciliate Magnetic *Uronema marinum* Mj1 that can graze and ingest different types of MTB. It's also affiliated to Uronematidae. we may find more ciliate species that grazing MTB in Uronematidae。

CONCLUSION

The results suggest that this ciliate species is capable of grazing and ingesting different types of MTB. These data reveal broad diversity and wide distribution of magnetically responsive protozoa and provide us more possibilities for researching the origin of magnetoreception in eukaryotes.

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