**Thioclava electrotropha** sp. nov., a versatile electrode and sulfur-oxidizing bacterium from marine sediments

Rachel Chang,¹ Lina Bird,¹ Casey Barr,¹ Magdalena Osburn,² Elizabeth Wilbanks,³ Kenneth Nealson¹ and Annette Rowe¹,4,*

**Abstract**

A taxonomic and physiologic characterization was carried out on Thioclava strain ElOx9T, which was isolated from a bacterial consortium enriched on electrodes poised at electron donating potentials. The isolate is Gram-negative, catalase-positive and oxidase-positive; the cells are motile short rods. The bacterium is facultatively anaerobic with the ability to utilize nitrate as an electron acceptor. Autotrophic growth with H₂ and S⁰ (oxidized to sulfate) was observed. The isolate also grows heterotrophically with organic acids and sugars. Growth was observed at salinities from 0 to 10% NaCl and at temperatures from 15 to 41 °C. Phylogenetic analysis based on 16S rRNA gene sequences indicated that the strain belongs in the genus *Thioclava*; it had the highest sequence similarity of 98.8% to *Thioclava atlantica* 13D2W-2T, followed by *Thioclava dalianensis* DLFJ1-1T with 98.5% similarity, *Thioclava pacifica* TL 2T with 97.7% similarity, and then *Thioclava indica* DT23-4T with 96.9%. All other sequence similarities were below 97% to characterized strains. The digital DNA–DNA hybridization estimated when compared to *T. atlantica* 13D2W-2T, *T. dalianensis* DLFJ1-1T, *T. pacifica* TL 2T and *T. indica* DT23-4T were 15.8±2.1, 16.7±2.1, 14.3±1.9 and 18.3±2.1%. The corresponding average nucleotide identity values between these strains were determined to be 65.1, 67.8, 68.4 and 64.4%, respectively. The G+C content of the chromosomal DNA is 63.4 mol%. Based on these results, a novel species *Thioclava electrotropha* sp. nov. is proposed, with the type strain ElOx9T (=DSM 103712T=ATCC TSD-100T).

The potential of micro-organisms to grow chemolithoautotrophically from solid phase minerals is poorly understood, and as such our appreciation for the environmental importance of these processes remains limited [1]. At present, there are a few cultured representatives that have been demonstrated to utilize mineral electron donors. To assess the potential for microbes to oxidise solid phase electron donors in marine sediments, an electrochemical cultivation scheme was devised and implemented [2]. Briefly, marine sediments were collected from Catalina Harbor (33° 25.23’ N, 118° 19.42’ W) in California, sieved through a 1000–500 μm copper mesh, and transferred to sediment microcosms. Indium tin oxide plated glass electrodes were placed in these sediment microcosms and maintained at poised electron donating potentials [tested between +197 and −203 mV versus SHE]. Biomass from these reactors was further enriched on solid mineral electron donors (e.g. S⁰, FeS, Fe⁰) [2]. A secondary enrichment of microbes using S⁰ as the electron donor coupled to nitrate as the terminal electron acceptor was performed to enrich sulfur-mineral oxidizers. Strain ElOx9T was isolated from this enrichment on artificial salt water media plates with 1.5% agar, with thiosulfate as the electron donor and nitrate as the electron acceptor. Strain ElOx9T oxidized thiosulfate to sulfate in this medium.

Subsequent electrochemical characterization was performed on strain ElOx9T using chronoamperometry—current measurements made over time at a controlled redox potential (Fig. S1, available in the online version of this article). To mimic zero valent sulfur oxidation, electrodes with strain...
**ELOx9** were poised at −100 to −300 mV vs SHE. These conditions fall within a biologically relevant range of redox potentials for elemental sulfur (−400 to +200 mV versus SHE depending on environmental conditions) and are slightly more negative than would be predicted for oxidation in traditional sea water conditions (pH 8) [2]. Strain ELOx9 was capable of coupling electrode oxidation (electron uptake, negative current generation) with oxygen reduction. Current increases initially, indicative of cell attachment within the first 12 h and gradually over the course of the 7 days incubation (Fig. S1a). Current production was linked to biological activity through addition of the cytochrome oxidase inhibitor cyanide, which was found to eliminate negative current production (Fig. S1b). To further characterize the ecological context of this micro-organism, phylogenetic and physiological characterization was pursued.

The genus *Thioclava* was first described by Sorokin *et al.* [3], with the isolation of the sulfur-oxidizing, facultative heterotroph, *Thioclava pacifica* TL 2<sup>T</sup>, from a near shore, sulfidic and hydrothermal area of the coast of Papua New Guinea. At the time of characterization of ELOx9, the genus included four type species, including *Thioclava pacifica* TL 2<sup>T</sup> [3], *Thioclava dalianensis* DLFJ1-1 [4], *Thioclava atlantica* 13D2W-2<sup>T</sup> [5] and *Thioclava indica* DT23-4<sup>T</sup> [6]. Of these strains, all but *T. dalianensis* DLFJ1-1<sup>T</sup> can grow chemolithoautotrophically with sulfur compounds [6]. Here, we describe the proposed species, *Thioclava electrotophra* ELOx9<sup>T</sup>, a bacterium that is capable of chemolithoautotrophic growth with poised solid-state electrodes, sulfur species and hydrogen. This organism can also grow as an organoheterotroph.

Initial cultures of *Thioclava* were grown in a salt water base media (SWB), as described by Rowe *et al.* [2]. Several modifications made to the original media were used, including an SWB with reduced sulfate concentrations (SWB-LS). Autotrophic growth experiments were performed in this media by providing either hydrogen gas, or elemental sulfur as described previously [7]. Cultures could also be grown heterotrophically in an enriched marine broth, Difco marine broth (DMB) (Becton Dickinson), however this media contains precipitates (making growth assays challenging) and so a particulate-free enriched media was designed. For morphological and biochemical characterization studies, a modified enriched medium based on LB, an LB +ions (LBI) media, was developed containing (per litre water): 10 g tryptone, 5 g yeast extract, 20 g NaCl, 3 g MgCl<sub>2</sub>*6H<sub>2</sub>O and 0.15 g CaCl<sub>2</sub>*2H<sub>2</sub>O. Agar (15 g per l) was added for solid medium. The amendment of ions CaCl<sub>2</sub>, NaCl and KCl allowed for optimal growth of strain ELOx9<sup>T</sup>. The physiological experiments testing temperature, pH and NaCl concentration utilized this rich media, but was slightly modified for pH and salinity experiments. The standard 20 g NaCl addition was modified for salinity tests (added 0–150 g per l to test 0–15% salinity) and 3.6 g MgSO<sub>4</sub>*7H<sub>2</sub>O and 0.17 g CaSO<sub>4</sub>*2H<sub>2</sub>O were added as divalent cation sources to prevent excess chloride addition. A 10 mM hydroxyethyl piperazineethanesulfonate (HEPES) buffer was added to pH experiments to stabilize pH from 3 to 7, and a 10 mM Tris/HCl buffer was added to stabilize the higher pH being tested.

Cultures for chronopotentiometry experiments were grown aerobically on LBI at 30 °C for 24 h. Culture were pelleted via centrifuge (5 min, 7500 r.p.m.), and resuspended in SWB-LS. Cells were washed in this method four times prior to inoculation into three-electrode electrochemical system as previously described [2]. A three-electrode system consists of an indium tin-oxide (ITO) coated glass working electrode, a Ag/AgCl reference and a Pt wire counter electrode, all submerged in 13 ml volume. The medium (SWB-LS) is constantly aerated during experiments. A Quadstat Potentiostat 500 (eDAQ) was used to apply a potential of −300 mV to the working electrode. A current baseline was measured for 30 min prior to inoculation. An additional SWB-LS was added to compensate for evaporation. At 185 h, −10 mM KCN was introduced to the system to distinguish biotic vs abiotic current generation.

The Gram stain was tested using the Gram-stain kit (Ward Science), following the manufacturer’s instructions. Catalase activity was assessed through the formation of bubbles after adding a drop of 3% H<sub>2</sub>O<sub>2</sub> to a colony. The oxidase test was performed by applying a drop of 1% tetramethyl-1,4-phe-nylenediamine dihydrochloride to a colony. General cell morphology was observed using cultures grown on LBI. Bacterial cultures for scanning electron microscope imaging were grown for 24 h under maximal growth conditions. Samples were fixed overnight at 4 °C in 8% glutaraldehyde diluted with growth media to a final concentration of 2.5%. Fixed cells were placed onto 0.2 µm membrane filters (Pall Corporation), and allowed to air dry for 15 min prior to ethanol dehydration. The dehydration series progressed from an initial wash concentration of 30% ethanol with 30 min stepwise increments to a final wash of 100% ethanol prior to critical point drying (Autosam dri-815, Toursimis). Fixed and dried samples were then sputter coated (Cressington) with approximately 3 nm of Pd. Electron micrographs were obtained with a JEOL-7001 FEG scanning electron microscope. Elemental sulfur associated cells were imaged live, via light microscopy and stained with SYBR green per manufacturer’s specifications (Molecular Probes, Thermofisher). Membrane lipids from strain ELOx9<sup>T</sup> as well as *T. dalianensis* DLFJ1-1<sup>T</sup> and *T. atlantica* 13D2W-2<sup>T</sup> were extracted and derivatized from freeze-dried cell pellets using a single step transesterification protocol [8]. Fatty acid methyl esters were identified and quantified using a Thermo Trace 1300 GC couple to a flame ionizing detector and an ISQ mass spectrometer.

Genomic DNA extraction was performed on 2 ml of cultures grown to an OD 600 nm of ~1.0 in enriched DMB. DNA was extracted using the MoBio UltraClean Microbial DNA extraction kit. PCR reactions using the 8F and 1492R primer sets were generated and prepared as described...
previously [2] for Sanger sequencing (Genewiz). Genomic DNA was prepared using Illumina’s Nextera XT sample preparation kit (FC-131-1096) and paired-end sequenced (250 bp reads) using the Illumina HiSeq platform at the UC Davis DNA Technologies Core Facility. Sequence data was filtered, trimmed and assembled using the A5-miseq pipeline [9], which conducts sequence adapter trimming and quality filtering sequences with Trimmomatic [10], read error correction using SGA’s k-mer-based error correction algorithm [11], and sequence assembly with IDBA-UD algorithm [12]. The assembled genome was further screened for contamination using NCBI VecScreen. Genome completeness and contamination was further verified with the checkM package [13]. The draft genome was annotated using the IMG-ER database and the NCBI Prokaryotic Genome Annotation Pipeline.

The ElOx9T isolate was Gram-negative, catalase-positive and oxidase-positive. Cells were short (1–2 µm long, 0.3–0.7 µm wide) and rod-shaped (Fig. S2a). Observations with light microscopy suggested motility. Growth on elemental sulfur induced biofilm formation around elemental sulfur particles (Fig. S2b).

Heterotrophic growth on glucose or acetate in minimal media as well as enriched media (LBI) was quantified (Fig. S3a). To test the utilization of various organic substrates as carbon sources, the Biolog GN2 Microplate System was used. The strain was grown on an LBI plate at 30°C for 24 h. Cell density was adjusted to an OD of 0.500 in an inoculating fluid containing 2.5% NaCl, 0.8% MgCl2 and 0.05% KCl. Duplicated Biolog microplates were inoculated with 100 µl of the cell suspension per well and incubated at 30°C. The results were read visually as previously described [14] and are summarized in Table S1. Strain ElOx9T utilized several organic compounds that had previously only been weakly metabolized by one or more Thioclava strain (e.g. glycogen, propionic acid, sucrose). However, there were no examples of substrates metabolised by all the other Thioclava strains and not the ElOx9T strain using the Biolog GN2 plate system (Table S1).

Further comparison of organic compound assimilation, as well as enzymatic reactivities was performed using the API 20NE and API ZYM test strips (bioMérieux) according to the manufacturer’s protocol for strain ElOx9T and its closest relatives T. atlantica 13D2W-2T, T. dalianensis DLFJ1-1T and T. indica DT23-4T. Malate was the only compound not assimilated by ElOx9T, but by all other tested strains (Table 1). Variation in utilization of glucose, arabinoase, mannose, mannitol, N-acetyl-glucosamine, maltose, gluconate and adipic acid was observed across the strains tested (Table 1). Overall, strain ElOx9T demonstrated a unique carbon substrate metabolism profile and moderate metabolic flexibility that has been observed within this genus. Anaerobic growth was determined using SWB amended with 5 mM sodium nitrate, excess acetate and approximately 1:500 dilution of cells in stoppered serum vials added in an anaerobic chamber. The ability of all the strains tested including ElOx9T to reduce nitrate to nitrite was confirmed in the API 20NE tests.

The oxidation of sulfur compounds (thiosulfate and sulfate) was tested on SWB plates containing 30 mM sodium sulfate, 25 mM sodium thiosulfate, 1.5% agar, and 0.002% bromothymol blue pH indicator. Oxidation of thiosulfate to sulfate was indicated in this minimal media through the production of acid. All strains, except T. dalianensis DLFJ1-1T generated a yellow colour under these conditions (Table 1). Similar electron uptake activities from electrodes was observed in T. dalianensis DLFJ1-1T and T. indica DT23-4T compared to ElOx9T. T. atlantica 13D2W-2T generated nearly 10-fold reduced activity (Table 1). All activities were sensitive to the inhibitor cyanide as described for ElOx9T. Similar electrochemical profiles were observed (current versus voltage relationships determined by cyclic voltammetry) in all the strains. Specifically, a similar onset potential from around 0 to −50 mV was consistent across strains, suggesting a similar enzymatic pathway for electrochemical activity (Fig. S4). Autotrophic growth was observed with elemental sulfur and thiosulfate in liquid SWB media with no exogenous carbon added. Autotrophic growth with formate (10 mM) and hydrogen (9.5 mM) was also tested in SWB media. No growth on formate was observed, though growth with hydrogen as an electron donor was quantified (Fig. S3b).

The optimal temperature for growth in strain ElOx9T was 37°C, though growth was observed from 15–41°C. Tolerance to NaCl was tested in LBI where NaCl concentration varied from 0–15%. Optimum growth was observed in 2% NaCl, but strain ElOx9T was able to grow over a salinity range of 0–10%. Growth with pH conditions were tested from pH 3.75–9.0. Strain ElOx9T grew from pH 4.5 to 8.5, with optimum growth observed at 6.5. These values fall within the values observed in several closely related Thioclava strains, but nevertheless offer a distinct growth profile (Table 1). The salinity optimum is slightly lower than natural sea water (~2%), which may reflect this organism’s adaptation to freshwater input into Catalina Harbor.

The major fatty acids produced by all the tested strains of Thioclava were similar and dominated by octadecenoic acid (81.8–87.0%), octadecanoic acid (4.7–7.9%) and hexadecanoic acid (0.7–2.8%) with lesser contributions of hexadecenoic acids, cyclopropyl fatty acids and hydroxyl fatty acids (Table 2). Our new results are similar lipid identifications measured previously for T. dalianensis DLFJ1-1T [4] and lipid abundances measured for T. atlantica 13D2W-2T [5] and indicate that under identical conditions these three strains produce very similar lipid profiles. Though T. indica DT23-4T or T. pacifica TL-2T were not sampled in parallel for comparison, previously published results are remarkably similar to those for strain ElOx9T [3, 6]. The specific abundance of each fatty acid detected is listed in Table 2.
Antibiotic susceptibility tests were performed using the disc-diffusion method as modified from Shieh et al. [15]. Overnight culture (100 µl) was spread onto each LBI plate. Six millimeter discs (Oxoid) with 20 µl antibiotic added were placed on the plates. Growth inhibition zones around the discs were recorded after aerobic incubation of the plates at 30°C for 24 h. When compared to the other species, all strains had the same sensitivities to kanamycin (30 µg ml⁻¹), gentamycin (10 µg ml⁻¹), ampicillin (10 µg ml⁻¹), tetracycline (30 µg ml⁻¹) and rifampicin (5 µg ml⁻¹). This strain was also sensitive to spectinomycin (50 µg ml⁻¹) and chloramphenicol (30 µg ml⁻¹). This strain differed in that it is resistant to streptomycin (10 µg ml⁻¹).

Phylogenetic analysis was performed based on the information gained from genome assembly, which contained approximately 70× coverage. The 16S rRNA sequence (MG208121) obtained from the complete sequence assembled from genomic DNA (GenBank accession GCA_002085925.1) shared 100 percent similarity with both the partial 16S rRNA sequence that was previously obtained ([2]; KM088033.1), and the nearly 12 000 bp sequence generated during this work via Sanger sequencing (MG866177). The 16S rRNA gene sequence similarity was determined using the EzBioCloud (www.ezbiocloud.net) [16]. Using the full 1473 bp 16S rRNA gene (MG208121), it was determined that this strain shared the highest 16S rRNA gene sequence similarity with both the partial 16S rRNA sequence previously obtained and the nearly 12 000 bp sequence generated during this work via Sanger sequencing (MG866177).

Table 1. Distinguishing phenotypic characteristics between strain EIOx9T and related Thioclava strains

<table>
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<tr>
<td>Motility</td>
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<td>−</td>
<td>−</td>
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<tr>
<td>Temperature range for growth (°C)</td>
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<td>10–45</td>
<td>10–37</td>
<td>10–37</td>
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<tr>
<td>Optimum temperature for growth (°C)</td>
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<td>28–37</td>
<td>28b</td>
<td>28–32</td>
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<td>NaCl tolerance range (% w/v)</td>
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<td>0.5–12</td>
<td>0.5–15</td>
<td>0–18</td>
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<tr>
<td>Optimum NaCl for growth (% w/v)</td>
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<td>3–5b</td>
<td>3b</td>
<td>3</td>
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<tr>
<td>pH range for growth</td>
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<td>4.5–8.5</td>
<td>4.5–8.5</td>
<td>5–8.5</td>
</tr>
<tr>
<td>Optimum pH for growth</td>
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<td>N.R. a</td>
<td>N.R. b</td>
<td>7</td>
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<tr>
<td>G+C content (mol%)</td>
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<td>65.3</td>
<td>62.5</td>
<td>60.3</td>
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<td>Sulfur oxidation to sulfate</td>
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<td>+</td>
<td>−</td>
<td>+</td>
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<td>Electrode oxidation</td>
<td>+</td>
<td>w</td>
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<td>API 20NE:</td>
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<tr>
<td>β-Galactosidase</td>
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<td>w</td>
<td>+</td>
<td>w</td>
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<td>Glucose</td>
<td>w</td>
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<td>w</td>
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<td>Arabinose</td>
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<tr>
<td>Mannose</td>
<td>w</td>
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<td>−</td>
<td>w</td>
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<td>−</td>
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<tr>
<td>Maltose</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>w</td>
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<td>Potassium gluconate</td>
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<td>Adipic acid</td>
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<td>Malate</td>
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<td>API ZYM:</td>
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<tr>
<td>Alkaline phosphatase</td>
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<td>Lipase (C 14), cystine arylamidase</td>
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<td>w</td>
<td>−</td>
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<td>Valine arylamidase</td>
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<td>Acid phosphatase</td>
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<td>w</td>
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<td>Napthol-AS-BI-phosphohydrolase</td>
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<td>α-Galactosidase</td>
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<tr>
<td>β-Galactosidase</td>
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<tr>
<td>β-Glucosidase</td>
<td>−</td>
<td>+</td>
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a, Data taken from [5].
b, Data taken from [4].
c, Data taken from [6].

Table 2. Percent cellular fatty acid composition of strain ElOx9T and related cultures

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tbody>
<tr>
<td>10:0-OH</td>
<td>1.2±0.4</td>
<td>1.2±0.2</td>
<td>1.5±0.5</td>
</tr>
<tr>
<td>cy-12</td>
<td>1.3±0.3</td>
<td>1.2±0.2</td>
<td>1.5±0.5</td>
</tr>
<tr>
<td>16:0</td>
<td>0.5±0.02</td>
<td>1.1±0.1</td>
<td>0.4±0.4</td>
</tr>
<tr>
<td>16:1</td>
<td>0.7±0.7</td>
<td>2.7±0.2</td>
<td>2.8±0.8</td>
</tr>
<tr>
<td>17:0</td>
<td>0.6±0.6</td>
<td>1.3±0.3</td>
<td>0.6±0.6</td>
</tr>
<tr>
<td>18:1</td>
<td>87±7</td>
<td>85.7±5.7</td>
<td>81.8±1.8</td>
</tr>
<tr>
<td>18:0</td>
<td>6.4±0.4</td>
<td>4.7±0.7</td>
<td>7.9±0.9</td>
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<tr>
<td>cy-18</td>
<td>0.8±0.8</td>
<td>0.8±0.8</td>
<td>0.5±0.5</td>
</tr>
<tr>
<td>cy-19</td>
<td>0.3±0.3</td>
<td>ND</td>
<td>0.6±0.6</td>
</tr>
<tr>
<td>18:0-OH</td>
<td>0.5±0.3</td>
<td>1.3±0.3</td>
<td>0.5±0.5</td>
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<tr>
<td>16:1</td>
<td>0.5±0.5</td>
<td>ND</td>
<td>0.5±0.5</td>
</tr>
</tbody>
</table>

*Fatty acid nomenclature in the form X:Y where X is the length of the carboxylic acid and Y is the number of unsaturations. cy- indicates the present of a cyclopropyl group where –OH indicates a hydroxyl group.

The digital DNA–DNA hybridization (dDDH) estimate values between the three strains were analysed using the Genome-to-Genome Distance Calculator (GGDC2.0) [17–19]. The average nucleotide identity (ANI) was calculated using the algorithm of Goris et al. [20] using the EzGenome web service. The estimated dDDH values between strain ElOx9T and, respectively, T. pacifica TL 2T, T. dalianensis DLFJ1-1T, T. atlantica 13D2W-2T and T. indica DT23-4T were 14.3±1.90, 16.70±2.1, 15.80±2.1 and 18.30±2.1 %, respectively, which are below the standard criteria (70 %) for delineation of bacterial species. The ANI values between Thioclava and the related type strains T. pacifica TL 2T, T. dalianensis DLFJ1-1T, T. atlantica 13D2W-2T and T. indica DT23-4T were 67.75, 68.43, 65.14 and 64.37 %, respectively. These values are below the standard ANI criteria for species identity of 95–96 % [21].

The G+C content of the chromosomal DNA was determined by the IMG analysis pipeline to be 63.8 mol%. This value is close to the G+C values of the other Thioclava species, which range from 63.1 mol% for T. pacifica TL 2T, 65.3 mol% for T. atlantica 13D2W-2T, 62.5 mol% for T. dalianensis DLFJ1-1T and 60.3 mol% for T. indica DT23-4T.

The high 16S rRNA gene similarity between strain ElOx9T and the other Thioclava species demonstrate that this strain belongs within the genus Thioclava. The results of phenotypic analysis and chemotaxonomic studies support the view that this strain should be assigned to the genus Thioclava. However, this strain can be differentiated from the four type species within this genus through the low values of dDDH and ANI, and biochemically with its distinct profile of organic compound utilization. Of note is this microbe’s ability to oxidize solid-state electrode surfaces, which has not specifically been demonstrated previously in this genus but may be a broadly conserved trait. Thus, this strain should be placed in a new species of genus Thioclava, for which Thioclava electrrotropha sp. nov. is proposed (=DSM 103712T=ATCC TSD-100T).

The similarity of 98.8 % to T. atlantica 13D2W-2T, 98.5 % to T. dalianensis DLFJ1-1T, 97.7 % to T. pacifica TL 2T, and 96.9 % to T. indica DT23-4T. Similarities to all other species were all below 95 %. These phylogenetic relationships were supported by maximum-likelihood analysis of the 16S rRNA gene, which further supports the ElOx9T strain designation as a Thioclava strain, within the Alphaproteobacteria (Fig. 1). It also confirms the closest relative to ElOx9T is T. atlantica 13D2W-2T.

The phylogenetic tree was constructed using the SINA web service. The estimated dDDH values between strain ElOx9T and, respectively, T. pacifica TL 2T, T. dalianensis DLFJ1-1T, T. atlantica 13D2W-2T and T. indica DT23-4T were 14.3±1.90, 16.70±2.1, 15.80±2.1 and 18.30±2.1 %, respectively, which are below the standard criteria (70 %) for delineation of bacterial species. The ANI values between Thioclava and the related type strains T. pacifica TL 2T, T. dalianensis DLFJ1-1T, T. atlantica 13D2W-2T and T. indica DT23-4T were 67.75, 68.43, 65.14 and 64.37 %, respectively. These values are below the standard ANI criteria for species identity of 95–96 % [21].
EMENDED DESCRIPTION OF THE GENUS
THIOCLAVA SOROKIN ET AL. 2005

Gram-negative rods of varying size from long filaments with swollen ends, clustered in aggregates, to single small rods, rarely motile. Grows heterotrophically with simple organic compounds. May or may not be obligately aerobic. May or may not be able to utilize hydrogen as an electron donor. Unable to grow methylotrophically. May or may not be facultatively autotrophic, sulfur-oxidizing, and/or able to grow autotrophically with thiosulfate. Autotrophic species contains the ‘green form’ of type I RubisCO, and inorganic carbon is assimilated via the Calvin cycle.

The type species of the genus is Thioclava pacifica.

DESCRIPTION OF THIOCLAVA
ELECTROTROPHA SP. NOV.

Thioclava electrotropha (e.lect.ro.tró’pha. Gr. n. electron amber, and N.L. electron electron; Gr. n. trophos feeder, rearer, that which nourishes; N.L. fem. adj. electrotropha feeding of electrons).

Cells are Gram-negative, rod-shaped and motile. Sizes range from 1 to 2 µm in length and 0.3–0.7 µm in width. Can form biofilms on mineral or electrode surfaces. Positive for catalase and oxidase. Oxidises hydrogen, elemental sulfur and thiosulfate for energy conservation. Grows autotrophically using sulfur compounds and hydrogen in the presence of oxygen. Does not grow on formate. Anaerobically grows on using sulfur compounds and hydrogen in the presence of oxygen. Does not grow on formate. Anaerobically grows on using sulfur compounds and hydrogen in the presence of oxygen. Does not grow on formate. Anaerobically grows on using sulfur compounds and hydrogen in the presence of oxygen.

The type strain, ElOx9T (=DSM 103712T=ATCC TSD-101T), was isolated from electrodes in Catalina Harbor sediment. Genome sequence data and annotations are publicly available at the JGI’s IMG portal (IMG Genome ID 2626541687). Genome data has been submitted to the NCBI WGS archive (GenBank accession GCA_002085925.1).

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Conflicts of interest
The authors declare that there are no conflicts of interest.

References


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