**Dethiosulfovibrio salsuginis** sp. nov., an anaerobic, slightly halophilic bacterium isolated from a saline spring

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A mesophilic, strictly anaerobic, slightly halophilic bacterium, designated strain USBA 82ᵀ, was isolated from a terrestrial saline spring in the Colombian Andes. The non-spore-forming curved rods (5–7×1.3 μm) with pointed or rounded ends, stained Gram-negative and were motile by means of laterally inserted flagella. The strain grew optimally at 30 °C (growth range 20–40 °C), pH 7.3 (growth range pH 5.5–8.5) and 2 % (w/v) NaCl (growth range 0.1–7 % NaCl). The strain fermented peptides, amino acids and a few organic acids, but growth was not observed on carbohydrates, alcohols or fatty acids. The strain reduced thiosulfate and sulfur to sulfide. Sulfate, sulfite, nitrate and nitrite were not used as electron acceptors. On peptone alone, acetate, succinate, propionate and traces of ethanol were formed, but in the presence of thiosulfate, acetate and succinate were formed. The G+C content of the chromosomal DNA was 52 mol% (Tm). 16S rRNA gene sequence analysis indicated that strain USBA 82ᵀ was affiliated to *Dethiosulfovibrio peptidovorans* within the phylum Synergistetes with a similarity value of approximately 93 %. Based on the differences between the new strain and the type species of the genus *Dethiosulfovibrio*, we suggest that strain USBA 82ᵀ represents a novel species of the genus for which the name *Dethiosulfovibrio salsuginis* sp. nov. is proposed. The type strain is USBA 82ᵀ (=DSM 21565ᵀ=KCTC 5659ᵀ).

The phylum *Synergistetes* (Jumas-Bilak et al., 2009) currently includes members of the genera *Dethiosulfovibrio*, *Synergistes*, *Anaerobaculum*, *Aminobacterium*, *Thermanaerovibrio*, *Aminomonas*, *Thermovigra*, *Aminophilus*, *Jonquettella* and *Cloacibacillus* (Rees et al., 1997; Baena et al., 1998, 1999a, b; Dahle & Birkeland, 2006; Díaz et al., 2007; Jumas-Bilak et al., 2007; Ganesan et al., 2008). A distinguishing feature that is common to all members of this phylum is the capacity to degrade amino acids (Vartoukian et al., 2007). *Dethiosulfovibrio peptidovorans* is the type species of the genus *Dethiosulfovibrio*. It was obtained by filtering saline spring water through polycarbonate membranes (Durapore) with a pore size of 0.22 μm. The medium was supplemented with peptone (0.2 %, w/v), yeast extract (0.02 %, w/v) and the trace element solution (1 ml l⁻¹) as described by Imhoff-Stuckle & Pfenning (1983). The medium was boiled and then cooled to room temperature under a stream of oxygen-free nitrogen. An 8 ml aliquot was dispensed into Hungate tubes under oxygen-free nitrogen gas and sterilized by autoclaving at 121 °C for 20 min at a pressure of 1–1.5 kg cm⁻². The enrichment medium was inoculated with 3 μl water samples, incubated at 36 °C for up to two weeks and examined by phase-contrast light microscopy (Eclipse 50i; Nikon).
To isolate pure cultures, serial dilutions of the enrichment cultures were made in an artificial basal medium (BM) fortified with 2 % (w/v) Noble agar using the roll-tube technique. BM contained (l
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deionized water): 1 g NH4Cl, 0.3 g K2HPO4, 0.3 g KH2PO4, 3 g MgCl2.6H2O, 0.1 g CaCl2.2H2O, 0.1 g KCl, 23 g NaCl, 1 ml trace element solution (Imhoff-Stuckle & Pfennig, 1983), 0.5 g cysteine-HCl, 1.0 g yeast extract and 0.5 % (w/v) peptone. The pH of the medium was adjusted to 7.1 with 1 M NaOH solution and then boiled, cooled and dispensed as described previously (Baena et al., 1998). Three morphologically similar cultures were isolated and 16S rRNA gene sequences of all of the isolates showed an identical sequence (100 % similarity). One of the three isolates, designated strain USBA 82T, was selected and studied further. The pure cultures were stored at −80 °C in glycerol-BM (20:80).

Cell morphology was determined by phase-contrast microscopy. Samples for electron microscopy were prepared as described by Patel et al. (1985). Cells of strain USBA 82T were slightly curved rods with pointed or rounded ends (5–7 × 1.5 μm) and occurred singly or in pairs. Cells stained Gram-negative and were motile by laterally inserted flagella. Spores were not observed and exponential phase cultures were killed when heated to 90 °C for 5 min.

All growth studies were performed in duplicate in BM as described above. The novel strain was subcultured at least once under the same experimental conditions before use. To investigate the pH range for growth, studies were performed in BM adjusted to pH values between 4.0 and 9.0 with anoxic stock solutions of NaHCO3 (10 %, w/v), Na2CO3 (10 % w/v) or citrate buffer (1 M). Strain USBA 82T grew between pH 5.5 and 8.5, with optimum growth at pH 7.3. The temperature range for growth was between 20 and 40 °C, with optimum growth occurring at 30 °C. To determine the NaCl tolerance of the strain, NaCl was added directly into the tubes to obtain the desired concentration and the BM was then added. Strain USBA 82T grew in concentrations of 0.1–7 % NaCl, but not in NaCl concentrations below 0.1 % or above 8 %. Cells grew optimally at 2 % NaCl (w/v).

Thiosulfate (10 mM), sulfate (10 mM), sulfite (5 mM), elemental sulfur (3 %, w/v), sodium nitrate (20 mM) and sodium nitrite (5 mM) were tested as electron acceptors in BM lacking yeast extract and supplemented with 0.2 % (w/v) peptone rather than the usual 0.5 % (w/v). H2S production from the reduction of sulfate, sulfite, elemental sulfur and thiosulfate was determined using the method of Cord Ruwisch (1985). The reduction of nitrate, nitrite and ammonia was determined as described by Ogg & Patel (2009). Strain USBA 82T was able to weakly reduce elemental sulfur and thiosulfate, but not sulfate, sulfite, nitrate or nitrite. Strain USBA 82T was unable to grow under aerobic conditions.

Substrate utilization tests were performed in the presence or absence of thiosulfate and sulfur in BM lacking peptone and amended with 0.025 % (w/v) yeast extract rather than 1.0 %. Substrates from autoclaved or filter-sterilized anaerobic stock solutions of monosaccharides, disaccharides, polysaccharides, sugar alcohols and peptides were added to a final concentration of 0.2 % (w/v) and organic acids and amino acids were added to a concentration of 10 mM. Growth was measured by inserting Hungate tubes into a Novaspec LKB spectrophotometer (Pharmacia-Biotech Pty. Ltd) and monitoring the optical density at 580 nm. Cultures were recorded as positive for growth if they exhibited an increase in optical density relative to controls (which lacked any added carbon sources). Strain USBA 82T fermented Casamino acids, peptone, tryptone, serine, histidine, threonine, arginine, glutamate, pyruvate and citrate. Growth did not occur on lysine, glycine, proline, valine, alanine, cysteine, leucine, isoleucine, lactate, succinate, formate, acetate, propionate, butyrate, fructose, cellobiose, xylose, glucose, mannose, mannotol, maltose, ribose, sucrose, lactose, galactose, arabinose, raffinose, glycerol, methanol, ethanol or inositol either in the presence or the absence of thiosulfate or sulfur.

End products from peptone fermentation and respiration were measured by HPLC (LC-20AT; Shimadzu Prominence) equipped with a reverse-phase C18 ultra aqueous column (150 mm × 4.6 mm ID) and a diode array detector (SPD-M20A) at 210 nm. The end products detected from peptone fermentation were acetate, succinate, propionate and traces of ethanol. In the presence of thiosulfate, the only end products detected were acetate and succinate.

Using the whole genome amplification method (Ogg & Patel, 2009), the G + C content of the DNA of strain USBA 82T was calculated to be 52 mol% (Tm).

DNA purification, PCR amplification and sequencing of the 16S rRNA gene were performed as described by Andrews & Patel (1996). Raw sequence data were imported into BioEdit, version 5.0.9 (Hall, 1999), the base calling was carefully examined and a contiguous consensus sequence of 1388 bp was generated. Using this consensus sequence, the closest relatives identified against the GenBank database (Altschul et al., 1997; Benson et al., 1999) using BLASTN and against the Ribosomal Database Project using the Sequence Aligner Program (Maidak et al., 2001) were downloaded. The sequences were aligned and positions of sequence and alignment ambiguity were omitted. A pairwise evolutionary distance matrix was generated using the method of Jukes & Cantor (1969) and a dendrogram was constructed using the neighbour-joining method (Saitou & Nei, 1987) as implemented in TREEDON (Van de Peer & De Wachter, 1994). Confidence in the tree topology was determined by using 1000 bootstraped trees (Felsenstein, 1985). Phylogenetic analysis placed strain USBA 82T in the phylum Synergistetes, closest to Dethiosulfovibrio peptidovorans DSM 11002T (93 % gene sequence similarity) (Magot et al., 1997) (Fig. 1).

Strain USBA 82T and D. peptidovorans DSM 11002T shared the ability to ferment yeast extract, peptone, tryptone,
Casamino acids, serine and histidine and the inability to use carbohydrates, fatty acids and organic acids as sole carbon and energy sources. Both strains reduced the electron acceptors sulfur and thiosulfate to sulfide. Sulfur or thiosulfate was obligately required by *D. peptidovorans* for growth on the amino acids arginine, glutamate and valine, but not by strain USBA 82T which grew on these amino acids fermentatively (Table 1). Strain USBA 82T could also be differentiated from *D. peptidovorans* by its ability to ferment threonine and citrate and its inability to use alanine, isoleucine and leucine in the presence or absence of sulfur or thiosulfate (Table 1). On the basis of its phenotypic characteristics, the phylogeny based on 16S rRNA gene sequence analysis and its G+C content, strain USBA 82T may be categorized as a novel member of the genus *Dethiosulfovibrio*, for which the name *Dethiosulfovibrio salsuginis* sp. nov. is proposed.

**Description of *Dethiosulfovibrio salsuginis* sp. nov.**

*Dethiosulfovibrio salsuginis* (sal.su’gi.nis. L. gen. n. salsuginis of salt water).

Cells stain Gram-negative and are slightly curved or vibrio-like rods with rounded or pointed ends, 5–7 × 1.5 μm. Cells are highly motile by means of lateral flagella. Endospores are not formed. Obligately anaerobic. Growth occurs in media containing 0.1–6.0 % (w/v) NaCl; 2% (w/v) is optimal for growth. NaCl is tolerated up to 7%, but no growth occurs at 8% or below 0.01%. The pH range of the strains is 5.5–8.5 (optimum 7.3) for strain USBA 82T and 5.5–8.8 (optimum 7.0) for strain *D. peptidovorans* DSM 11002T. Both strains reduce sulfur and thiosulfate to sulfide, but do not reduce sulfate to sulfide.

**Table 1.** Physiological characteristics of strain USBA 82T and the type species of the genus *Dethiosulfovibrio*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Strain USBA 82T (data from Magot et al., 1997)</th>
<th>Strain <em>D. peptidovorans</em> DSM 11002T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling site</td>
<td>Saline spring (Corroding offshore oil well)</td>
<td>Corroding offshore oil well</td>
</tr>
<tr>
<td>Cell morphology</td>
<td>Curved rods or spirals</td>
<td>Curved rods or spirals</td>
</tr>
<tr>
<td>Cell size (µm)</td>
<td>1.5 × 5–7</td>
<td>1 × 3–5</td>
</tr>
<tr>
<td>DNA G+C content (mol%)</td>
<td>52</td>
<td>56</td>
</tr>
<tr>
<td>Temp. range (optimum) (°C)</td>
<td>20–40 (30)</td>
<td>20–45 (42)</td>
</tr>
<tr>
<td>NaCl range (% w/v) (optimum)</td>
<td>0.1–7 (2)</td>
<td>(3)</td>
</tr>
<tr>
<td>pH range (optimum)</td>
<td>5.5–8.5 (7.3)</td>
<td>5.5–8.8 (7.0)</td>
</tr>
<tr>
<td>Utilization of:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alanine</td>
<td>–</td>
<td>+¹</td>
</tr>
<tr>
<td>Arginine</td>
<td>+</td>
<td>+¹</td>
</tr>
<tr>
<td>Citrate</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Cysteine</td>
<td>–</td>
<td>ND</td>
</tr>
<tr>
<td>Glutamate</td>
<td>+</td>
<td>+¹</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>–</td>
<td>+¹</td>
</tr>
<tr>
<td>Leucine</td>
<td>–</td>
<td>+¹</td>
</tr>
<tr>
<td>Lysine</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Pyruvate</td>
<td>+</td>
<td>ND</td>
</tr>
<tr>
<td>Threonine</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Valine</td>
<td>–</td>
<td>+¹</td>
</tr>
</tbody>
</table>
for growth is 5.5–8.5 with an optimum at pH 7.3. The temperature range for growth is 20–40 °C with an optimum at 30 °C. The type strain is able to reduce elemental sulfur (weakly) and thiosulfate when growing on peptone, but is not able to reduce sulfate, sulfite, nitrate or nitrite. Ferments pyruvate, citrate, Casamino acids, peptone, tryptone, serine, histidine, threonine, arginine and glutamate. Growth does not occur on lysine, glycine, proline, valine, alanine, cysteine, leucine, isoleucine, lactate, succinate, formate, acetate, propionate, butyrate, fructose, cellobiose, xylose, glucose, mannose, mannitol, maltose, ribose, sucrose, lactose, galactose, arabinose, raffinose, glycerol, methanol, ethanol or inositol either the presence or the absence of thiosulfate or sulfur. The main end products of fermentation are acetate and succinate.

The type strain, USBA 82T (=DSM 21565T=KCTC 5659T), was isolated from the Salpa saline spring. The DNA G+C content of the type strain is 52 mol%.

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References


