Haloterrigena daqingensis sp. nov., an extremely haloalkaliphilic archaeon isolated from a saline–alkaline soil

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A haloalkaliphilic archaeon, strain JX313^T, was isolated from a saline–alkaline soil from Daqing, Heilongjiang Province, China. Its morphological, physiological and biochemical features and 16S rRNA gene sequence were determined. Colonies of the strain were orange–red and cells were non-motile cocci and Gram-stain-variable. The strain required at least 1.7 M NaCl for growth, with optimal growth occurring in 2.0–2.5 M NaCl. Growth was observed at 20–50 °C and pH 8.0–10.5, with optimal growth at 35 °C and pH 10.0. The G + C content of its genomic DNA was 59.3 mol%. Phylogenetic analysis of 16S rRNA gene sequences showed that strain JX313^T is associated with the genera *Haloterrigena* and *Natrinema* and is most closely related to *Haloterrigena salina* XH-65^T (96.2% sequence similarity) and *Haloterrigena hispanica* FP1^T (96.2%). DNA–DNA hybridization experiments revealed that the relatedness of strain JX313^T to type strains of related species of the genus *Haloterrigena* or *Natrinema* was less than 50%. Furthermore, the cellular polar lipids of strain JX313^T, identified as phosphatidylglycerol, phosphatidylglycerol phosphate methyl ester and mannose-2,6-disulfate (1→2)-glucose glycerol diether (S₂-DGD), were consistent with the polar lipid characteristics of the genus *Haloterrigena*. Therefore, phylogenetic analysis, phenotypic assessment and chemotaxonomic data showed that JX313^T represents a novel species within the genus *Haloterrigena*, for which the name *Haloterrigena daqingensis* sp. nov. is proposed. The type strain is JX313^T (=CGMCC 1.8909^T =NBRC 105739^T).

Halophilic archaea belonging to the order *Halobacteriales* are found in large numbers in saline and hypersaline environments worldwide (Kamekura & Dyall-Smith, 1995; Oren *et al.*, 1997; Grant, 2004; Fendrihan *et al.*, 2006). On the basis of phylogenetic analysis and DNA–DNA hybridization data, the genus *Haloterrigena* was established by Ventosa *et al.* (1999) and the first proposed species was *Haloterrigena turkmenica* (formerly *Halococcus turkmenicus*). In recent studies, some novel members of the genus

Haloterrigena have been proposed on the basis of conventional physiological, biochemical and chemical characteristics and through phylogenetic analysis based on 16S rRNA gene sequences and DNA–DNA hybridization results. At the time of writing, the genus *Haloterrigena* comprises eight species of extremely halophilic archaeon, namely *Htg. turkmenica* (Ventosa *et al.*, 1999), *Htg. thermotolerans* (Montalvo-Rodríguez *et al.*, 2000), *Htg. saccharevitans* (Xu *et al.*, 2005b), *Htg. longa* and *Htg. limicola* (Cui *et al.*, 2006), *Htg. hispanica* (Romano *et al.*, 2007), *Htg. salina* (Gutiérrez *et al.*, 2008) and *Htg. jeotgali* (Roh *et al.*, 2009). In this study, an aerobic haloalkaliphilic archaeon designated strain JX313^T was isolated. The characterization and taxonomy of strain JX313^T are described, and the results indicate that strain JX313^T represents a novel species of the genus *Haloterrigena*.

Strain JX313^T was isolated by enrichment culture from a soil sample collected from the surface (0–10 cm) of a soda

Abbreviation: S₂-DGD, mannose-2,6-disulfate (1→2)-glucose glycerol diether.

The GenBank/EMBL/DDBJ accession number for the 16S rRNA gene sequence of strain JX313^T is FJ545273.

A phase-contrast photomicrograph, TLC of polar lipids, minimum-evolution and maximum-parsimony phylogenetic trees and soil chemical characteristics are available as supplementary material with the online version of this paper.

meadow saline soil in Daqing, Heilongjiang Province, China (46° 34' N 125° 07' E) in July 2007. To the best of our knowledge, this is the first incidence of a haloalkaliphilic archaeon being isolated from this region.

To isolate haloalkaliphilic archaea, soil sediment was serially diluted in double-distilled water and then spread on a modified S-G agar medium (Sehgal & Gibbons, 1960) with the following composition (l⁻¹ distilled water): 10 g yeast extract, 7.5 g Casamino acids, 3.0 g trisodium citrate, 2.0 g KCl, 0.2 g MgSO₄·7H₂O, 0.036 g FeSO₄·7H₂O, 200 g NaCl, 10.0 g Na₂CO₃ and 20.0 g agar. Sodium carbonate was sterilized separately and then added to the medium. The medium was adjusted to pH 9.5 with NaHCO₃/Na₂CO₃ buffer. Plates sealed in plastic bags were incubated at 37 °C. After 7 days of incubation, representative colonies were transferred to the same medium. A pure culture was obtained by repeated streaking. Phenotypic tests were performed according to the proposed minimal standards for the description of new taxa in the order *Halobacteriales* (Oren *et al.*, 1997). The optimal conditions for growth were determined in liquid S-G medium with 0.85–5.1 M NaCl. The pH range for growth (assayed from pH 5.0 to 11.0 at intervals of 0.5 pH units) was determined by adding MES (pH 5.0–6.0), PIPES (pH 6.5–7.0), Tricine (pH 7.5–8.5), CHES (pH 9.0–9.5) or CAPS (pH 10.0–11.0) to S-G medium at a concentration of 50 mM. The temperature range for growth of strain JX313^T was determined in S-G medium at optimal NaCl concentration and pH. Growth was monitored as the OD₆₀₀. Cell morphology and motility were examined by optical and phase-contrast microscopy (BH51; Olympus). Colony morphology was analysed on solid medium by stereomicroscopy (SZ1145TR; Olympus). Gram staining was performed using acetic acid-fixed samples, as described by Dussault (1955).

Anaerobic growth was tested in the presence of nitrate, L-arginine or DMSO (each at 5 g l⁻¹) in filled stoppered tubes. Gelatin hydrolysis was determined as described by Oren *et al.* (2002). The following characteristics were tested according to Xin *et al.* (2000) and Oren *et al.* (1997): hydrolysis of starch, casein and Tween 20, 40, 60 and 80, nitrate reduction, production of indole and H₂S, catalase and oxidase activities and utilization of sugars, alcohols, amino acids and organic acids.

Total lipids were extracted by using a modified method of Kamekura & Kates (1988). Phospholipids and glycolipids were separated by TLC on silica gel plates (10 × 10 cm) and analysed according to description of Xin *et al.* (2000). Genomic DNA was prepared by the method of Marmur (1961) and the purity was checked spectrophotometrically. The DNA G+C content was determined by thermal denaturation (*T*_m) (Marmur & Doty, 1962) using *Escherichia coli* K-12 DNA as a calibration standard. The 16S rRNA gene sequence was amplified under conditions described by Feng *et al.* (2005) and the primer sequences referred to by Xu *et al.* (2005b). Sequence similarity was analysed by comparing the 16S rRNA gene sequence of

strain JX313^T with known sequences from the GenBank database using the BLASTN program. Sequence data were aligned with CLUSTAL W software, version 1.8 (Thompson *et al.*, 1994). Phylogenetic trees were reconstructed by using the neighbour-joining, maximum-parsimony and minimum-evolution methods with the MEGA3 program package (Kumar *et al.*, 2004). To evaluate the stability of the phylogenetic trees, a bootstrap analysis (1000 replications) was performed with the programs SEQBOOT, DNADIST, NEIGHBOR and CONSENSE in the PHYLIP software package. DNA–DNA hybridization was performed by using the thermal denaturation and renaturation method of De Ley *et al.* (1970) as modified by Huß *et al.* (1983).

A novel aerobic, extremely haloalkaliphilic archaeon, strain JX313^T, was isolated from soda meadow saline soil. The properties of the isolation habitat (soil) provided evidence that a high total salt concentration was required for growth of this micro-organism (see Supplementary Table S1, available in IJSEM Online). Cells of strain JX313^T were coccoid and occurred singly or in pairs or irregular clusters (Supplementary Fig. S1), Gram-stain-variable and non-motile. Colonies on agar medium after incubation at 37 °C for 7 days were light red. Strain JX313^T was able to grow at 1.7–5.5 M NaCl, 20–50 °C and pH 8.0–10.5. Detailed results of phenotypic and antibiotic susceptibility tests are included in the species description and Table 1.

Sequence similarity analysis of the 16S rRNA gene showed that strain JX313^T was closely related to *Haloterrigena salina* XH-65^T (96.2 % similarity), *Htg. hispanica* FP1^T (96.2 %), *Htg. turkmenica* VKM B-1734^T (95.7 %), *Htg. limicola* AX-7^T (95.6 %), *Htg. longa* ABH32^T (95.5 %), *Htg. thermotolerans* PR5^T (95.5 %), *Htg. jeotgali* A29^T (95.1 %), *Htg. saccharovitans* AB14^T (94.4 %), *Natrinema versiforme* XF10^T (95.7 %), *Nnm. gari* HIS40-3^T (95.7 %), *Nnm. ejinorensis* EJ-57^T (95.4 %), *Nnm. pallidum* NCIMB 777^T (95.4 %), *Nnm. pellirubrum* NCIMB 786^T (95.3 %) and *Nnm. altunense* AJ2^T (95.0 %). The phylogenetic tree constructed by the neighbour-joining method is shown in Fig. 1, indicating that strain JX313^T clustered with recognized species of the genera *Haloterrigena* and *Natrinema*. The phylogenetic position of strain JX313^T was also confirmed in trees generated using the minimum-evolution and maximum-parsimony algorithms (Supplementary Fig. S2).

Strain JX313^T and the reference strain *Htg. thermotolerans* CGMCC 1.3709^T were cultured at 37 °C for 6 days and polar lipids were extracted. Polar lipid analysis indicated that strain JX313^T contained phosphatidylglycerol, phosphatidylglycerol phosphate methyl ester and mannose-2,6-disulfate (1→2)-glucose glycerol diether (S₂-DGD) as the main glycolipids (Supplementary Fig. S3). Because of the phylogenetic overlap between *Haloterrigena* and *Natrinema*, the taxonomic problems of the two genera deserve in-depth study (Montalvo-Rodríguez *et al.*, 2000; Oren & Ventosa, 2002). Previous studies have shown that there are differences in the polar lipid composition among species of the two genera. *Haloterrigena* species contain the glycolipids

Table 1. Characteristics that distinguish strain JX313^T from type strains of species of the genus *Haloterrigena*

Strains: 1, JX313^T; 2, *Htg. jeotgali* DSM 18794^T; 3, *Htg. salina* JCM 13891^T; 4, *Htg. hispanica* DSM 18328^T; 5, *Htg. longa* CGMCC 1.5334^T; 6, *Htg. limicola* CGMCC 1.5333^T; 7, *Htg. saccharovitans* CGMCC 1.3730^T; 8, *Htg. thermotolerans* CGMCC 1.3709^T; 9, *Htg. turkmenica* JCM 8891^T. Data for JX313^T and *Htg. hispanica* DSM 18328^T were obtained in our laboratory. Data for lysis in distilled water, H₂S production, indole formation, hydrolysis of Tweens and carbon source utilization of all strains except *Htg. jeotgali* DSM 18794^T were obtained from the CGMCC. Other data were taken from Roh *et al.* (2009), Gutiérrez *et al.* (2008), Cui *et al.* (2006), Xu *et al.* (2005b), Montalvo-Rodríguez *et al.* (2000) and Ventosa *et al.* (1999). +, Positive; –, negative; NR, not reported.

Characteristic	1	2	3	4	5	6	7	8	9
Cell morphology	Coccoid	Rods	Coccoid	Coccoid	Rods	Rods	Rods/coccoid	Rods	Coccoid
Motility	–	–	–	–	–	+	+	–	–
Cell size (μm)	0.8–1.3	0.4 × 1.0	1.2–1.6	1.5–2.0	0.5–0.6 × 2.8–11	0.6–0.8 × 1.8–3.6	3.0–10.0 × 0.4–1.0	4.0–13.0 × 0.7–1.0	1.5–2.0
NaCl range (M)	1.7–5.5	1.7–5.1	2.5–5.0	2.2–4.0	1.7–5.1	1.7–5.1	>1.7	2.0–4.5	>2.0
Lysis in distilled water	–	+	–	+	+	+	+	+	–
Temperature optimum (°C)	35	37–45	37	50	41–45	40–45	42–45	50	45
Growth at pH 7.0	–	+	+	+	+	+	+	+	+
Growth at pH 10.0	+	–	–	–	–	–	–	–	–
Oxidase	–	–	+	+	+	+	+	+	NR
H ₂ S production	+	NR	–	+	+	+	+	+	–
Use of sugars as carbon source	–	+	+	–	+	–	–	–	+
Indole formation	–	+	–	+	+	–	–	–	–
Hydrolysis of:									
Tween 20	+	NR	+	–	+	+	+	+	NR
Tween 40	+	NR	–	–	+	–	+	+	NR
Tween 60	+	NR	+	–	+	–	–	–	NR
Tween 80	+	+	+	–	–	–	–	+	NR
DNA G + C content (mol%)	59.3	62.3	67.0	62.0	62.3	61.9	66.6	63.3	59.8

S₂-DGD (Cui *et al.*, 2006; Gutiérrez *et al.*, 2008; Montalvo-Rodríguez *et al.*, 2000; Roh *et al.*, 2009; Ventosa *et al.*, 1999; Xu *et al.*, 2005b) or mannose-6-sulfate (1→2)-glucose

glycerol diether (S-DGD) (Romano *et al.*, 2007), but most *Natrinema* species have phosphatidylglycerol sulfate and unidentified glycolipids (McGenity *et al.*, 1998; Tapingkae

Fig. 1. Neighbour-joining phylogenetic tree, based on 16S rRNA gene sequences, showing the relationship between strain JX313^T and related taxa. The tree was constructed using MEGA3 (Kumar *et al.*, 2004). Bootstrap values (%) are based on 1000 replicates and are shown for branches with more than 70% bootstrap support. Bar, 0.02 expected changes per site.

et al., 2008; Xin *et al.*, 2000; Xu *et al.*, 2005a). Therefore, it is reasonable to conclude that strain JX313^T should be classified as a member of the genus *Haloterrigena* based on the higher 16S rRNA gene sequence similarities to members of the genus, clustering with members of the genus *Haloterrigena* in phylogenetic trees based on the 16S rRNA gene sequence and the presence of S₂-DGD.

The DNA G + C content of strain JX313^T was 59.3 mol%, which lies within the range reported for the genus *Haloterrigena* (59.2–67.0 mol%; Oren *et al.*, 2009). DNA–DNA relatedness of strain JX313^T with respect to *Htg. salina* JCM 13891^T, *Htg. hispanica* DSM 18328^T, *Htg. longa* JCM 13563^T and *Nnm. ejinorensis* CGMCC 1.6202^T was 41.6, 32.8, 21.2 and 17.2 %, respectively.

On the basis of the phylogenetic, genotypic, chemotaxonomic and phenotypic data, it is suggested that strain JX313^T should be classified as the type strain of a novel species of the genus *Haloterrigena* with the name *Haloterrigena daqingensis* sp. nov.

Description of *Haloterrigena daqingensis* sp. nov.

Haloterrigena daqingensis (da.qing.en'sis. N.L. fem. adj. *daqingensis* pertaining to Daqing, north-east China, where the type strain was isolated).

Cells are coccoid, 0.8–1.3 µm in diameter. Non-motile, occurring singly or in pairs or irregular clusters. Cells do not lyse in distilled water. Many cells are Gram-negative and a few others stain Gram-positive in young cultures. Colonies are 1–2 mm in diameter after 7 days of incubation on S-G medium at 37 °C, orange-pigmented, smooth, circular and convex. Haloalkaliphilic; growth occurs in 1.7–5.5 M NaCl (optimum at 2.0–2.5 M NaCl), at pH 8.0–10.5 (optimum at pH 10.0) and at 20–50 °C (optimum at 35 °C). Chemo-organotrophic and aerobic. Oxidase-negative and catalase-positive. Anaerobic growth does not occur with nitrate, arginine or DMSO. Nitrate reduction to nitrite is not observed. H₂S is produced from Na₂S₂O₃. Indole formation is negative. Negative for caseinase, amylase and gelatinase. Tweens 20, 40, 60 and 80 are hydrolysed. The following substrates are utilized as carbon sources: glycerol, acetate, pyruvate, succinate, aspartate and glutamate. Glucose, maltose, fructose, sucrose, trehalose, mannose, D-xylose, lactose, D-ribose, rhamnose, galactose, cellobiose, arabinose, starch, mannitol, sorbitol, inositol, citrate, lactate, fumarate, arginine, lysine, alanine and glycine are not utilized for growth. Acid is produced from glycerol only. Sensitive to (µg per disc) rifampicin (5), ciprofloxacin (5), erythromycin (15) and novobiocin (30). Resistant to (µg per disc, unless otherwise indicated): streptomycin (10), tetracycline (30), vancomycin (30), kanamycin (30), lincomycin (2), neomycin (30), ampicillin (10), chloramphenicol (30), norfloxacin (10), penicillin G (10 IU) and bacitracin (0.04 IU). The major polar lipids are phosphatidylglycerol, phosphatidylglycerol methyl ester and S₂-DGD. The DNA G + C content of the type strain is 59.3 mol% (*T*_m).

The type strain, JX313^T (=CGMCC 1.8909^T =NBRC 105739^T), was isolated from a saline and alkaline soil of Daqing, Heilongjiang, China.

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References

- Cui, H. L., Tohty, D., Zhou, P. J. & Liu, S. J. (2006). *Haloterrigena longa* sp. nov. and *Haloterrigena limicola* sp. nov., extremely halophilic archaea isolated from a salt lake. *Int J Syst Evol Microbiol* **56**, 1837–1840.
- De Ley, J., Cattoir, H. & Reynaerts, A. (1970). The quantitative measurement of DNA hybridization from renaturation rates. *Eur J Biochem* **12**, 133–142.
- Dussault, H. P. (1955). An improved technique for staining red halophilic bacteria. *J Bacteriol* **70**, 484–485.
- Fendrihan, S., Legat, A., Pfaffenhuemer, M., Gruber, C., Weidler, G., Gerbl, F. & Stan-Lotter, H. (2006). Extremely halophilic archaea and the issue of long-term microbial survival. *Rev Environ Sci Technol* **5**, 203–218.
- Feng, J., Zhou, P., Zhou, Y.-G., Liu, S.-J. & Warren-Rhodes, K. (2005). *Halorubrum alkaliphilum* sp. nov., a novel haloalkaliphile isolated from a soda lake in Xinjiang, China. *Int J Syst Evol Microbiol* **55**, 149–152.
- Grant, W. D. (2004). Introductory chapter: half a lifetime in soda lakes. In *Halophilic Microorganisms*, pp. 17–22. Edited by A. Ventosa. Heidelberg: Springer.
- Gutiérrez, M. C., Castillo, A. M., Kamekura, M. & Ventosa, A. (2008). *Haloterrigena salina* sp. nov., an extremely halophilic archaeon isolated from a salt lake. *Int J Syst Evol Microbiol* **58**, 2880–2884.
- HuB, V. A. R., Festl, H. & Schleifer, K. H. (1983). Studies on the spectrophotometric determination of DNA hybridization from renaturation rates. *Syst Appl Microbiol* **4**, 184–192.
- Kamekura, M. & Dyal-Smith, M. L. (1995). Taxonomy of the family *Halobacteriaceae* and the description of two new genera *Halorubrobacterium* and *Natrialba*. *J Gen Appl Microbiol* **41**, 333–350.
- Kamekura, M. & Kates, M. (1988). Lipids of halophilic archaeobacteria. In *Halophilic Bacteria II*, pp. 25–54. Edited by F. Rodriguez-Valera. Boca Raton, FL: CRC Press.
- Kumar, S., Tamura, K. & Nei, M. (2004). MEGA3: integrated software for molecular evolutionary genetics analysis and sequence alignment. *Brief Bioinform* **5**, 150–163.
- Marmur, J. (1961). A procedure for the isolation of deoxyribonucleic acid from microorganisms. *J Mol Biol* **3**, 208–218.
- Marmur, J. & Doty, P. (1962). Determination of the base composition of deoxyribonucleic acid from its thermal denaturation temperature. *J Mol Biol* **5**, 109–118.
- McGenity, T. J., Gemmell, R. T. & Grant, W. D. (1998). Proposal of a new halobacterial genus *Natrinema* gen. nov., with two species

- Natrinema pellirubrum* nom. nov. and *Natrinema pallidum* nom. nov. *Int J Syst Bacteriol* **48**, 1187–1196.
- Montalvo-Rodríguez, R., López-Garriga, J., Vreeland, R. H., Oren, A., Ventosa, A. & Kamekura, M. (2000). *Haloterrigena thermotolerans* sp. nov., a halophilic archaeon from Puerto Rico. *Int J Syst Evol Microbiol* **50**, 1065–1071.
- Oren, A. & Ventosa, A. (2002). International Committee on Systematics of Prokaryotes Subcommittee on the taxonomy of *Halobacteriaceae*. Minutes of the meetings, 24 September 2001, Seville, Spain. *Int J Syst Evol Microbiol* **52**, 289–290.
- Oren, A., Ventosa, A. & Grant, W. D. (1997). Proposal of minimal standards for the description of new taxa in the order *Halobacteriales*. *Int J Syst Bacteriol* **47**, 233–238.
- Oren, A., Elevi, R., Watanabe, S., Ihara, K. & Corcelli, A. (2002). *Halomicrobium mukohataei* gen. nov., comb. nov., and emended description of *Halomicrobium mukohataei*. *Int J Syst Evol Microbiol* **52**, 1831–1835.
- Oren, A., Arahall, D. R. & Ventosa, A. (2009). Emended descriptions of genera of the family *Halobacteriaceae*. *Int J Syst Evol Microbiol* **59**, 637–642.
- Roh, S. W., Nam, Y. D., Chang, H. W., Kim, K. H., Sung, Y., Kim, M. S., Oh, H. M. & Bae, J. W. (2009). *Haloterrigena jeotgali* sp. nov., an extremely halophilic archaeon from salt-fermented food. *Int J Syst Evol Microbiol* **59**, 2359–2363.
- Romano, I., Poli, A., Finore, I., Huertas, F. J., Gambacorta, A., Pelliccione, S., Nicolaus, G., Lama, L. & Nicolaus, B. (2007). *Haloterrigena hispanica* sp. nov., an extremely halophilic archaeon from Fuente de Piedra, southern Spain. *Int J Syst Evol Microbiol* **57**, 1499–1503.
- Sehgal, S. N. & Gibbons, N. E. (1960). Effect of some metal ions on the growth of *Halobacterium cutirubrum*. *Can J Microbiol* **6**, 165–169.
- Tapingkae, W., Tanasupawat, S., Itoh, T., Parkin, K. L., Benjakul, S., Visessanguan, W. & Valyasevi, R. (2008). *Natrinema gari* sp. nov., a halophilic archaeon isolated from fish sauce in Thailand. *Int J Syst Evol Microbiol* **58**, 2378–2383.
- Thompson, J. D., Higgins, D. G. & Gibson, T. J. (1994). CLUSTAL W: improving the sensitivity of progressive multiple sequence alignment through sequence weighting, position-specific gap penalties and weight matrix choice. *Nucleic Acids Res* **22**, 4673–4680.
- Ventosa, A., Gutiérrez, M. C., Kamekura, M. & Dyll-Smith, M. L. (1999). Proposal to transfer *Halococcus turkmenicus*, *Halobacterium trapanicum* JCM 9743 and strain GSL-11 to *Haloterrigena turkmenica* gen. nov., comb. nov. *Int J Syst Bacteriol* **49**, 131–136.
- Xin, H., Itoh, T., Zhou, P., Suzuki, K., Kamekura, M. & Nakase, T. (2000). *Natrinema versiforme* sp. nov., an extremely halophilic archaeon from Aibi salt lake, Xinjiang, China. *Int J Syst Evol Microbiol* **50**, 1297–1303.
- Xu, X. W., Ren, P. G., Liu, S. J., Wu, M. & Zhou, P. J. (2005a). *Natrinema altunense* sp. nov., an extremely halophilic archaeon isolated from a salt lake in Altun Mountain in Xinjiang, China. *Int J Syst Evol Microbiol* **55**, 1311–1314.
- Xu, X. W., Liu, S. J., Tohty, D., Oren, A., Wu, M. & Zhou, P. J. (2005b). *Haloterrigena saccharevitans* sp. nov., an extremely halophilic archaeon from Xin-Jiang, China. *Int J Syst Evol Microbiol* **55**, 2539–2542.