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Isolation of cDNAs Encoding Subunits *A* and *B* of the Vacuolar-Type ATPase from the Vanadium-Rich Ascidian, *Ascidia sydneiensis samea*

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ABSTRACT—Vacuolar-type H⁺-ATPases (V-ATPases), which are composed of at least ten different subunits, can generate a proton-motive force by hydrolyzing ATP and acidify the contents of various intracellular organelles. Subunits *A* and *B* of V-ATPase have been detected immunologically in ascidian blood cells, predominantly in signet ring cells (vanadocytes), which accumulate vanadium in their vacuoles. The action of V-ATPase in ascidian blood cells has been demonstrated by the fact that bafilomycin A₁, a specific inhibitor of V-ATPases, inhibits the acidification of the vacuoles of vanadocytes. As the next step in studying the function of V-ATPase in vanadocytes, we isolated cDNAs encoding subunits *A* and *B* of V-ATPase from the blood cells of an ascidian, *Ascidia sydneiensis samea*. The nucleotide sequences of the cDNAs for subunits *A* and *B* encoded proteins of 619 and 509 amino acids, respectively, both of which were highly conserved among organisms.

INTRODUCTION

The blood cells of ascidians, especially those in the family Ascidiidae in the suborder Phlebobranchia, accumulate extremely high levels of vanadium from seawater (Henze, 1911). At the same time, the homogenate of the blood cells has been revealed to be extremely acidic (Henze, 1911, 1912, 1913, 1932). Most of the vanadium ions in the vanadocytes are in the +3 oxidation state (Hirata and Michibata, 1991). These unusual phenomena have attracted the interest of investigators because of the possible role of the highly acidic environment in changing or maintaining the redox potential.

Previously, we found that there is a correlation between the concentration of vanadium(III) ions and the pH within the vacuole (Michibata *et al.*, 1991). In *Ascidia gemmata*, which is known to contain the highest concentration of vanadium at 350 mM, the vacuoles have the lowest pH of 1.86. Vacuoles of *A. ahodori* containing 60 mM vanadium have a pH of 2.67, and those of *A. sydneiensis samea* containing 13 mM vanadium have a pH of 4.20 (Michibata *et al.*, 1991).

Immunocytological studies, using antibodies against subunits *A* and *B* of the vacuolar-type H⁺-ATPases (V-ATPases) originated from bovine chromaffin granules, have shown that V-ATPases are localized in the vacuolar membranes of

vanadocytes (Uyama *et al.*, 1994). A specific inhibitor of V-ATPases inhibits the proton pump in the vacuoles of the vanadocytes, neutralizing the vacuoles' contents (Uyama *et al.*, 1994). Thus, one definite function of V-ATPases is to accumulate protons in the vanadocytes. However, it is difficult to explain the extremely low pH observed in ascidian vacuoles by only the action of V-ATPases, since the maximum Δ pH that a V-ATPase can generate under typical physiological conditions is around 4 pH units, based on measured H⁺/ATP stoichiometry (Rea and Sanders, 1987).

We have proposed that two mechanisms may be responsible for the proton accumulation in vanadocytes. One is the hydrolysis of the water molecules coordinating with the vanadium(III) ions. In our recent study, we showed that an extremely low pH could be achieved by hydrolysis of the water molecules coordinating with vanadium(III) ions (Kanamori *et al.*, unpublished data). The other mechanism involves the extremely tight coupling of ATP hydrolysis and proton pumping by V-ATPase in the vanadocytes. As a first step to assess the latter possibility, we isolated and analyzed cDNA of subunits *A* and *B* of V-ATPase from the blood cells of the vanadium-rich ascidian, *Ascidia sydneiensis samea*.

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MATERIALS AND METHODS

PCR amplification

A cDNA library of the blood cells of *A. sydneiensis samea* has been constructed in Uni-Zap XR vector (Stratagene, USA) (Uyama *et al.*, 1998). Lambda phage DNA was extracted from the amplified cDNA library. Degenerate primers were designed from conserved regions of subunits A and B of V-ATPase. For subunit A, the forward primer was 5'- AT(A/C/T) GT(A/C/G/T) TT(C/T) GC(A/C/G/T) GC(A/C/G/T) ATG -3' and the reverse primer was 5'- (A/G)TC (A/C/G/T)GT (A/G) TA CAT (A/G)TA (A/C/G/T)CC -3'. For subunit B, the forward primer was 5'- AT(A/C/T) GT(A/C/G/T) TT(C/T) GC(A/C/G/T) GC(A/C/G/T) ATG -3' and the reverse primer was 5'- (A/G)TC (A/C/G/T)GT (A/G) TA CAT (A/G)TA (A/C/G/T)CC -3'. PCR conditions were as follows: 0.2 µg lambda phage DNA, 200 pmole each primer, 0.2 mM dNTP, 25 mM Tris-HCl (pH 8.3), 50 mM KCl and 1.5 mM MgCl₂. The reaction volume was 50 µl. 30 cycles of PCR were run; each cycle consisted of 94°C for 45 sec, 50°C for 45 sec and 72°C for 45 sec. This was followed by a final extension at 72°C for 5 min. Amplified DNA fragments of the expected length (126 bp for subunit A and 306 bp for subunit B) were cloned into pBluescript SK(-) vector (Stratagene) and sequenced.

Screening of a cDNA library

The same cDNA library was screened with digoxigenin-labeled random-primed DNA probes derived from the cloned PCR fragments. Hybridization was done at 50°C (subunit A) or 65°C (subunit B) for at least 16 hr in 0.25 M disodium hydrogenphosphate buffer (Na-Pi buffer, pH 7.2), 7% SDS, 1 mM EDTA and 10 ng/ml probes. The membranes were washed three times in 20 mM Na-Pi buffer (pH 7.2), 1% SDS at 40°C (subunit A) or 65°C (subunit B). They were treated with anti-digoxigenin-AP conjugate (Boehringer Mannheim, Germany). The signals were detected by chemiluminescence using CSPD substrates (Boehringer Mannheim) and Hyper-ECL film (Amersham Pharmacia Biotech, Sweden). Positive plaques were screened again before they were subcloned. The cDNAs were excised as plasmids *in vivo* according to the manufacturer's protocol. Nucleotide sequences were determined using an ABI 377 automated sequencer (Perkin-Elmer Applied Biosystems, USA) or an ALFexpress automated sequencer (Amersham Pharmacia Biotech).

5'-RACE of subunit A cDNA

Oligonucleotides, 5'- TAG TTG GAG CGA AAT CCC AC -3' (R1), complementary to the 5' region of cDNA clone #104 of subunit A of V-ATPase (VATA) were synthesized. The lambda phage DNA from the cDNA library was again used for amplifying a longer 5'-stretch of VATA cDNA. cDNA fragments corresponding to the 5' region of VATA cDNA were amplified by PCR with the specific primer R1 and a common primer T3, but they did not reach the expected 5'-end of the cDNA. Therefore, another oligonucleotide, 5'- CAG TTC GGA ATG GCC TAC AC -3' (R2), was designed complementary to the cDNA fragment amplified from the cDNA library. The 5'-RACE was performed with a 5'/3' RACE Kit (Boehringer Mannheim) according to the manufacturer's protocol. Briefly, total RNA was extracted from blood cells except for giant cells as described (Uyama *et al.*, 1998). Two micrograms of total RNAs were reverse-transcribed with R1 primer. The cDNA products were used as templates for PCR with R2 and anchored dT primers supplied by the manufacturer. The PCR products were cloned into pBluescript SK(-) vector and sequenced.

RESULTS

Cloning cDNA for V-ATPase subunit A

We amplified 126-bp cDNA fragments corresponding to V-ATPase subunit A from the cDNA library constructed from

whole blood cells of the ascidian *A. sydneiensis samea*. Three clones of subunit A were isolated, and were revealed to contain almost identical fragments. Within the amplified region, the ascidian and bovine amino acid sequences were identical at 23 residues out of 30. Using one of the PCR fragments as a probe, we isolated two cDNA clones for subunit A out of 6×10^4 phages from the cDNA library of *Ascidia sydneiensis samea* blood cells. We designated the corresponding gene as the ascidian VATA gene. The two cDNA clones had almost identical nucleotide sequences. Comparisons of the open reading frame (ORF) of one of the cDNA clones (clone number #104) with those of VATA genes from other organisms showed that cDNA clone #104 seemed to lack a 5'-region corresponding to roughly one-hundred amino acids.

In order to isolate the missing region, we designed two specific primers complementary to the cDNA, and amplified this region directly from the cDNA library and a blood cell cDNA pool (see Materials and Methods). The 3'-part of the amplified fragments was identical to the 5'-part of clone #104. We combined the amplified sequences with that of cDNA clone #104 to generate a cDNA sequence for the VATA gene (Fig. 1).

The assembled VATA cDNA was composed of 2,253 nucleotides including a 21-bp poly(A) tail. The cDNA contained a single, long ORF of 1,860 nucleotides including the termination codon. It encoded a protein of 619 amino acids. The calculated molecular mass of the predicted protein was 69.0 kDa, which showed a good correlation to the expected molecular weight of 70 kDa determined by western blot analyses using antibodies against the 72K subunit (subunit A) derived from bovine chromaffin granules (Uyama *et al.*, 1994). The deduced amino acid sequence showed a striking similarity to the known 72K subunit of V-type ATPases from various organisms (Fig. 2). There was 81.7% amino acid identity between the ascidian and the bovine sequence and 68.1% identity between the ascidian and yeast sequence, excluding the intein that is spliced into a DNA endonuclease (Gimble and Thorner, 1992). The nucleotide-binding P-loop motif, GXXXXGKT (Saraste *et al.*, 1990), was also found in the ascidian VATA cDNA (Figs. 1, 2).

Cloning the cDNA of subunit B

We used a similar procedure to clone subunit B cDNA. We cloned and determined the sequences of eight PCR fragments amplified from the same blood cell cDNA library. The identity of the nucleotide sequences between the fragments was at least 93% (data not shown). Within the amplified region, the ascidian and bovine amino acid sequences were at least 95% identical. Using one of the PCR fragments as a probe, two positive clones were isolated out of 6×10^4 phages. Both were almost identical and contained a nearly full-length cDNA. We designated the corresponding gene as VATB and determined the complete nucleotide sequence of one of the cDNA clones (#105, Fig. 3).

The ascidian VATB cDNA clone had an insert of 2,017 nucleotides. The insert contained a single, long open reading frame of 1,530 nucleotides including the termination codon,

1	GAATAAGCCAACATTTGTATAATAGTCATAGAGGGAATATTAATTCTGCTAAAATGAAGCAAGAGGCTTAT	72
1		6
		M K Q E A Y
73	CAAATTCCCAAAATCCAGGATATGAAAAGGAAAGCATGCTGGGGACTGTGTTTGGTGTATCTGGTCCAGTC	144
6	Q I P K I Q D M E K E S M L G T V F G V S G P V	30
145	GTGACTGCCGAGCACATGTCTGGATCTCCATGTACGAGCTGGTTCGTGTAGGCCATTCCGAAGTGGTGGGA	216
30	V T A E H M S G S S M Y E L V R V G H S E L V G	54
217	GAGATCATTCGTCTTGATGGTGTATCGTGTACAATTCAGTATACGAAGAAACATCTGGCGTAACTGTGTCG	288
54	E I I R L D G D R A T I Q V Y E E T S G V T V G	78
289	GATCCTGTGTGAGAAGTGGAAAGCCTTTGTCCGTAGAAATGGGGCCTGGAATTTTGAACAACATCTATGAT	360
78	D P V L R T G K P L S V E L G P G I L N N I Y D	102
361	GGTATTCAGCGTCCCTGGAAGTTATCCAACAGCAGACCAAGTCAATTTACATTCCTCGTGGTGTAAACACG	432
102	G I Q R P L E V I Q Q Q T K S I Y I P R G V N T	126
433	TTAGCTTTGAACCGCAGTGTCTCAGTGGGATTTCCGCTCCAACATAAGCATTCACAGTGGGAAGTCAATCACT	504
126	L A L N R S A Q W D F A P T K A F Q V G S H I T	150
505	GGTGGGGACATCTACGGTCTGATTACGAAAACCTTTGATTCAACACAGGGTTCATGCTCCCTCCATAAAGCA	576
150	G G D I Y G L I Q E N S L I Q H R V M L P P K A	174
577	CGAGGACGAGTTACTTACGTGCTGAAGCTGGCCACTACAATGTTGATGACACCCTATTGGAGGTGGAGTTC	648
174	R G R V T Y V A E A G H Y N V D D T L L E V E F	198
649	GATGGCGTTGTCAAGAAGTACAGCATGCTGCAAGTCTGGCCTGTCCGTCACCCAGACCCTGTGTGGAGAAG	720
198	D G V V K K Y S M L Q V W P V R Q P R P C V E K	222
721	CTGCCAGCTAATTAACCTCTTCTCACTGGGCAGAGAGTCTTGGATGCTCTGTTCCCATCCGTCACGGGGGC	792
222	L P A N Y P L L T G P R V L D A L F P S V Q G G	246
793	ACCACCGCATCCAGGCGCTTCGGCTGTGGCAAGCAGTTCATCTCCAGTCCGCTCTCGAAATCTCCAAC	864
246	T T G I P <u>G A F G C G K T</u> V I S Q S L S K F S N	270
865	AGCGACATCATCGTCTACGTGGGCTGCGGTGAGCGTGGCAACAGATGTCGGAAGTCTGAGAGATTTCCCC	936
270	S D I I V Y V G C G E R G N E M S E V L R D F P	294
937	GAGTGCACCGTCTACATGTACGGGAGGGAAGAATCCATCATGAAACGTACCACCGTGGTGGCAACACATCG	1008
294	E L T V Y M Y G R E E S I M K R T T L V A N T S	318
1009	AACATGCCCGTCCCGCTAGAGAGGCTTCCATTTACACTGGAATCACCTTGTCCGAATACTTCCGTGATATG	1080
318	N M P V A A R E A S I Y T G I T L S E Y F R D M	342
1081	GGATAACCGTGTCCATGATGGCCGACTCGACGTCTCGATGGGCCGAGGCTCTTCGTGAGATCTCCGGTCTG	1152
342	G Y N V S M M A D S T S R W A E A L R E I S G R	366
1153	CTTGCCGAGATGCCCGGACTCCCGCTACCCCGCTACTTGGGTGCCAGGCTGGCTTCTTCTACGAGCGA	1224
366	L A E M P A D S G Y P A Y L G A R L A S F Y E R	390
1225	GCCGGCCGCTCACGTGCCAGGGAAGTCCCAGCCGGAAGGCAGCGCTCCCTCGTCCGAGCTGTGTCCGCC	1296
390	A G S R V T C Q G S P S R E G S V S L V G A V S P	414
1297	CCCGTGTGTACTTTTCGGATCCTGTACGTCAGCGCGGCGCTCGGTATCGTCCAGGCTTCTTGGGCTGTGGAC	1368
414	P G G D F S D P V T S A T L G I V Q V F W G L D	438
1369	AAGAAGCTCGCCAGCGAAAGCACTTTCTTCGGTCAACTGGCTGATCAGTTACTCCAACATACATGAGATCG	1440
438	K K L A Q R K H F P S V N W L I S Y S N Y M R S	462
1441	CTGGACGACTTCTACGACAAGAATAACCCGACTTCTGTTCCACTCCGTGTCAAGTCAAGGAGATCCTCCAG	1512
462	L D D F Y D K N Y P D F V P A L R V K V K E I L Q	486
1513	GAGGAAGAGGAGTCTCCGAAATCGTCCAGCTCGTCCGAAAAGTCCCTCCGCGAGACCGCAAAATCACG	1584
486	E E E E L S E I V Q L V G K S S L A E T D K I T	510
1585	CTGGAGGTCCCAAGATCATCAAGGACGATTTCTGCAGCAAAACGGCTTTTTCGGCTTACGACAGGTACTGC	1656
510	L E V A K I I K D D F L Q Q N G F S A Y D R Y C	534
1657	CCCTTCTACAAAACCGTCCGATGATCCGCAACATGATCGCTTTCTACGACATGGCGCGCCAGCGTGGAG	1728
534	P F Y K T V G M I R N M I A F Y D M A R A S V E	558
1729	TCGACCCCGAGTCCGACAACAAGATCACCTGGGCGATACACGCGAAAACCTGAGCGACATCCTGTACCGG	1800
558	S T A Q S D N K I T W A I I R E N L S D I L Y R	582
1801	CTCTCGTGTGAAAGTTCAAGGACCCGATCAAGGACGGGAGGCGAAGATCAAGCGGAAATCGAGCAGCTC	1872
582	L S S M K F K D P I K D G E A K I K R E I E Q L	606
1873	TACGACGACATGCAAAAACGGCTTCAGGAATTTGGAAGAATAGCGATTTTTTTTCTCGTTCTCCGATTGTT	1944
606	Y D D M Q N G F R N L E E *	619
1945	TTTTGTGTTTGTTCGAGGACCGCTTTTCGACGACCGACCGACCGCCCGCTGCAATATTTTCAGGCTTCGTCT	2016
2017	CTTTTTTTGACCTTCGAGCACCAGGTCACGACCTTGGGCTCCCGCTAAAAGTCCCTCTCGTCCCGTTC	2088
2089	GTGATCCCGGTGATCCTGCCGCCCGGATCCCAAGTTCGCTGATTCGTTTGTGGCACTCCCGTTCG	2160
2161	GAATAAAAAAACAATTTATGTGCGTAAACAGAAAAAATTTACGCTTTGGTTATACACAGGGCTGTGTCTTT	2232
2233	AAAAAAAAAAAAAAAAAAAAA	2253

Fig. 1. Nucleotide and amino acid sequences of VATA cDNA assembled from cDNA clone #104 and two 5'-RACE products from *Ascidia sydneiensis samea*. The regions corresponding to the forward and reverse primers are shown by dotted lines. The P-loop motif is underlined. Clone #104, isolated by the cDNA library screening, starts at the 376th nucleotide of this sequence, the first round 5'-RACE product at the 124th nucleotide, and the second round product at the 1st nucleotide. This sequence is stored in the DDBJ, GenBank, and EMBL nucleotide databases under accession number AB016483.

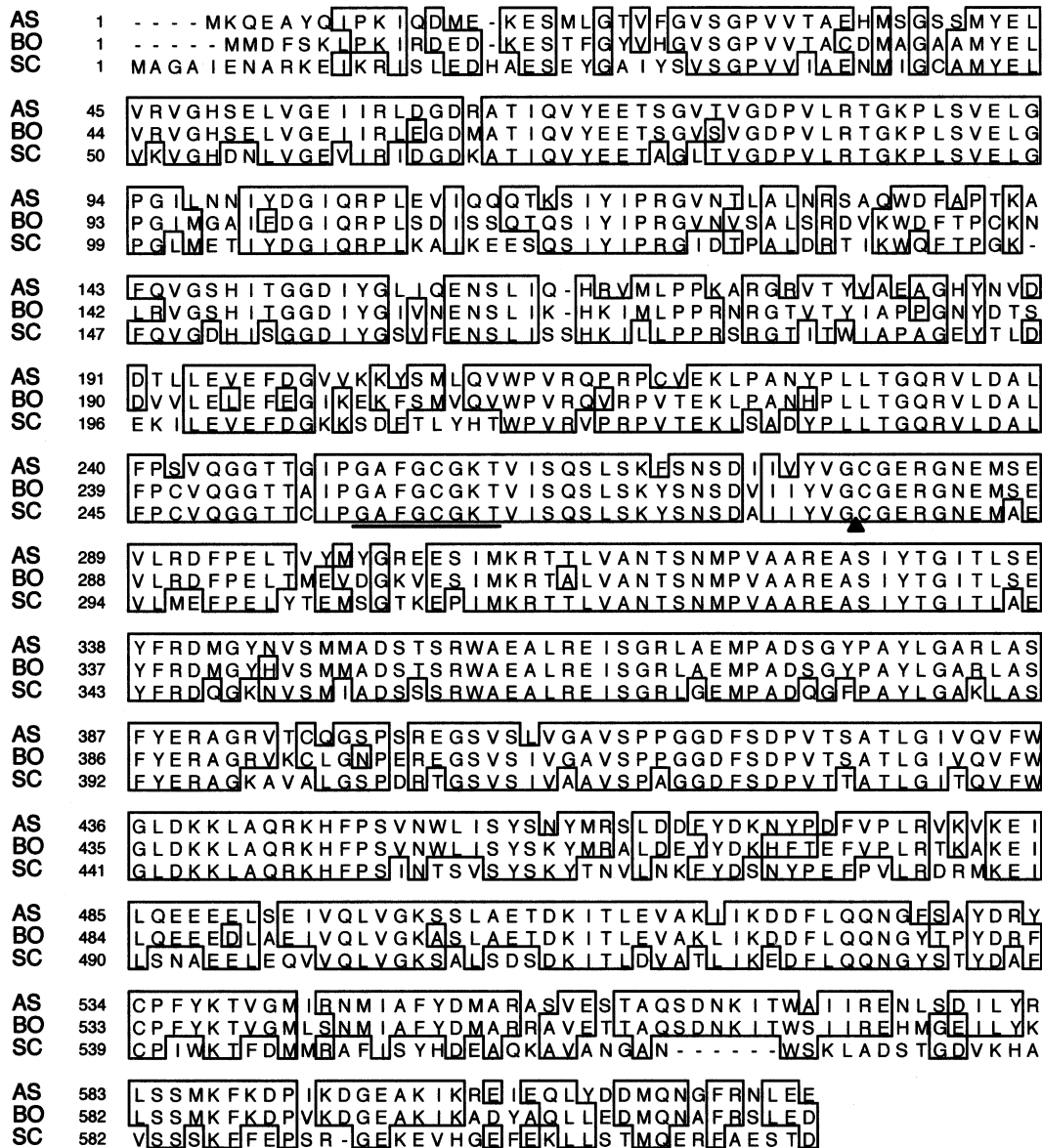


Fig. 2. Alignment of the amino acid sequences of subunit A of V-ATPases from various organisms. Identical residues are boxed. The P-loop motif is underlined. The solid triangle shows the position of protein splicing, which generates a DNA endonuclease (Gimble and Thorner, 1992) in yeast. Abbreviations: AS, *Ascidia sydneiensis samea* (this study); BO, bovine (Puopolo *et al.*, 1991); SC, budding yeast (Hirata *et al.*, 1990).

encoding a protein of 509 amino acids. Its calculated molecular mass was 56.7 kDa, which also showed a good correlation to the molecular weight of the antigen detected by anti bovine subunit B antibody (Uyama *et al.*, 1994). The deduced amino acid sequence of the *VATB* cDNA was very similar to known sequences of V-ATPase subunit B from various organisms (Fig. 4).

DISCUSSION

V-ATPases that can generate a proton-motive force by hydrolyzing ATP are known to acidify the contents of various intracellular organelles including clathrin-coated vesicles, endosomes, lysosomes, Golgi-derived vesicles, multivesicular

bodies and chromaffin granules that belong to the central vacuolar system, and to make an electrochemical gradient of H⁺ linked to the uptake of certain small molecules (Forgac, 1989, 1992; Nelson, 1992). We are focusing our attention on the close relationship between the high concentration of protons and the high level of vanadium in vanadocytes (Michibata *et al.*, 1991), which may provide a key to clarify the energetics of the accumulation of vanadium in ascidians.

In this experiment, we successfully isolated full-length cDNAs of subunits A and B of the V-ATPase from the vanadium-rich ascidian *Ascidia sydneiensis samea*. Since antibodies against subunits A and B from bovine chromaffin granules detected antigens specific to vanadocytes (Uyama *et al.*, 1994), we suppose that these cDNAs were derived from the

1	TCTACATCATTGCATCTTGTCAAAATAGATCAAAATGGCCACCACGTTAGACATGGCCCAACTTTCTGCAGC	72
1		
	M A T T L D M A Q L S A A	13
73	TAAAGAGCACGCTTTGGCTGTGAGCAGAGATTACATTTCCAGCCACGTTTAAACATACCAAACCGTATCCGG	144
13	K E H A L A V S R D Y I S Q P R L T Y Q T V S G	37
145	TGTCAACGGGCCGCTGGTCAATTTGGAAAAAGTGAAGTTTGCTAAGTTCCGCCGAAATTTGTAACCTTGAACCTT	216
37	V N G P L V I L E K V K F A K F A E I V T L N L	61
217	GGCTGACGGTACACAGCGCAGTGGACAGGTGCTGGAAGTCAGTGGAGACAAAGCTGTCTGCCAGGTGTTTCGA	288
61	A D G T Q R S G Q V L E V S G D K A V V Q V F E	85
289	AGGCACGTGAGTATTGATGCCAACACACAACATGCCAGTTCACGGGCGACATTTTAAGGATTTCCAACCTC	360
85	G T S G I D A K H T T C G E F T G D I L R I P T S	109
361	GGAAGACATGCTCGTTCGTATCTTCAACGGATCTGGAAAACCGATCGACAAGGGGCCATCTGTTTTGCCTGA	432
109	E D M L G R I F N G S G K P I D K G P S V L P E	133
433	AGACTACTTGGATATTCAGGGTTCAGCCATTAATCCCAAGTCTCGTATTTACCCAGAGGAGATGATTCAAAC	504
133	D Y L D I Q G Q P I N P K S R I Y P E E M I Q T	157
505	TGGCATCTCTGCCATTGACACCATGAACAGCATCGCTCGTGGACAGAAAATTTCCCATCTTCTCCGCTAATGG	576
157	G I S A I D T M N S I A R G Q K I P I F S A N G	181
577	TTTGGCCGACAACGAAATCGCCGCCAGATTTGTCRACAGGGCGGTTTGGTCAAGCTCCCTGACAAGGACGT	648
181	L P H N E I A A Q I C R Q G G L V K L P D K D V	205
649	CATGACAGTACAGGAGCAACTTTGCTATTTGTTTCGCTGCTATGGGTGTAACATGGAAGCAGCTAGATT	720
205	M D S H E D N F A I V F A A M G V N M E A A R F	229
721	TTTCAAGTCCGACTTTGAGCAGCACGGCTCCATGGACAACGTGTGCCCTTTCCTTAACCTTGCAAACGATCC	792
229	F K S D F E Q H G S M D N V C L F L N L A N D P	253
793	GACCATTTGAGAGGATCATTACACCTCGTATTCGACTTACGACTGTGAGTTCCTGGCCTACCAGTGCAGAA	864
253	T I E R I I T P R I A L T T A E F L A Y Q C E K	277
865	GCACGTGCTGGTCACTCCACCGACATGAGTTCCTATGCTGAAGCTCTGAGAGAGGTGTCAGCCGCCAGAGA	936
277	H V L V I L T D M S S Y A E A L R E V S A A R E	301
937	GGAGGTGCCCGGTCGTCGTGGTTTCCCGGTTACATGTACACGGATTTTGCACCATCTACGAGCGAGCCGG	1008
301	E V P G R R G F P G Y M Y T D L A T I Y E R A G	325
1009	TCGTGTCAACGGCAGAAACGGATCCATCACCCAGATTTCCATTCTCACTATGCCAACGACGATATTACCCA	1080
325	R V N G R N G S I T Q I P I L T M P N D D I T H	349
1081	TCCCATTCCCGATTTGACCGGTTACATTACCGAGGGACAGATCTACATCGACAGGCAGCTGCACAACAGGCA	1152
349	P I P D L T G Y I T E G Q I Y I D R Q L H N R Q	373
1153	GATCTACCCGCCATCAACGTCCTGCCTTCCCGTCTCATGAAGTCCGCCATCGGCGAGGGAATGAC	1224
373	I Y P P I N V L P S L S R L M K S A I G E G M T	397
1225	CAGAAAGGACCACTCCGACGTTTCCAACCAGCTGTACGCTAACTACGCCATCGGAAAGGACGTCAGGCTAT	1296
397	R K D H S D V S N Q L Y A N Y A I G K D V Q A M	421
1297	GAAGCCGTCGTCGGCGAGGAGGCTTAACCGCAGACGATGCTTTACTTGGAGTTCCTGGGCAATTCGA	1368
421	K A V V G E E A L T A D D M L Y L E F L G K F E	445
1369	GAAGACCTTTATCGCGCAAGGTCCTGACGAGAACCAGCGCTTTCGACTCGCTCAACATCGGCTGGGAGCT	1440
445	K T F I A Q G P Y E N R S V F D S L N I G W E L	469
1441	CCTGCCAATTTCCCAAGGAGTGTGAAGCGAATCCCGGGAACGTCATCAACGAGTACTACCCGAGAAA	1512
469	L R I F P K E M L R R I P R N V I N E Y Y P R K	493
1513	GAAGGTGCCCTCCGCCAGGACAAGCAGGAGGACCAGAAGGAAGAGAAGTGAGCGAGAGAGAGAGGCCGACC	1584
493	K V P S A Q D K Q E D Q K E E K *	509
1585	GTAGAAGAAGAAAAGAGAGAGAGAAATTATCTCGCTTTTTTCGCCCTTTTTTCTTTTTTCGATCGTTCGTTTC	1656
1657	TCGTGTTTTCTCTTTTTCCGCTTCTGTTTCGTATCAGTTTTTTTTTTTCAACCAGATTCACCTAGAGCACCTT	1728
1729	CAAAGGTCGCGACGAAACCCGAAAAGCACGAAATGTGAGCGCGCACGTAGCTTTTCTCGCTTAGACGCTTCCG	1800
1801	TATTCGCTCGCCCTCATCCAGACTCGACTTCCCCCCCCTAACGCAGCAAAACGCCTCCTTTCCAAACTACG	1872
1873	GTGTTGCTCTATTGATGCTCGTCTGTTCTGTTTGCCTCCCGCCCTTGAGGTCCCGTCTCGTCCGTGTGGAAC	1944
1945	ATGTCGCGAAACCGATTCTGTTTGTGTGCAATAAAAGCTATCCGCACAGAAAAA	2016
2017	A	2017

Fig. 3. Nucleotide and amino acid sequence of *VATB* cDNA clone #105 isolated from *Ascidia sydneiensis samea*. The regions corresponding to the PCR primers are shown by dotted lines. This cDNA sequence is stored in the DDBJ, GenBank, and EMBL nucleotide databases under accession number AB016484.

transcripts in the vanadocytes. The subunit composition and cDNA sequences of V-ATPases in various living organisms have been reviewed (Finbow and Harrison, 1997) and some differences in these V-ATPases related to intracellular components or the species of living organisms have been reported. In general, V-ATPase is composed of at least five different subunits, denoted as subunits *A* to *E*. Of these, direct chemi-

cal labeling and sequence homology studies show that subunits *A* and *B* play an important role in binding and catalyzing ATP. The highly conserved amino acid sequences of subunits *A* and *B* in living organisms imply that they have important roles. In some organisms, more than one isoform has been reported for each subunit. There are two isoforms of subunit *A* in the human and chick, and two of subunit *B* in the

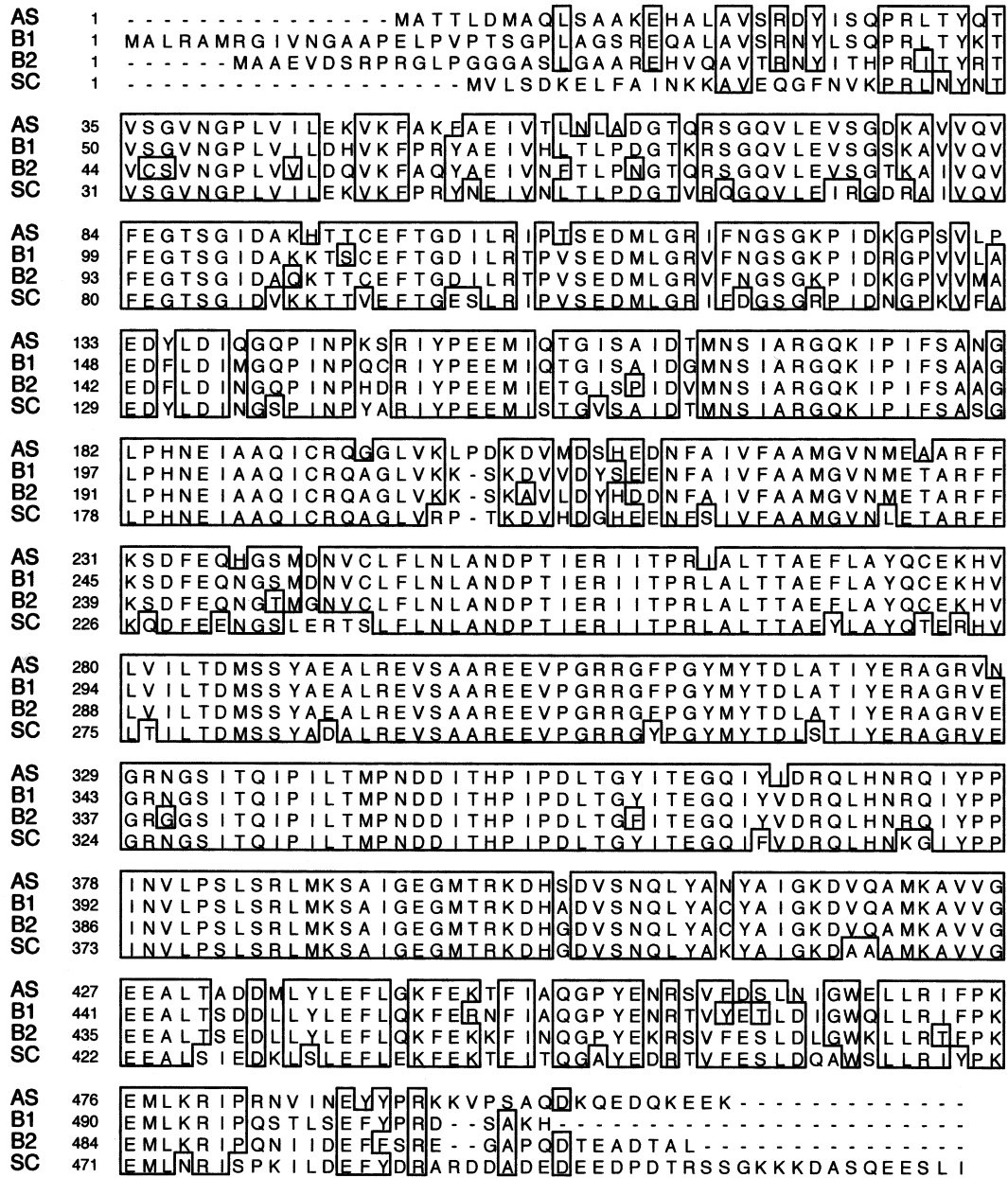


Fig. 4. Alignment of the amino acid sequences of subunit *B* of V-ATPases from various organisms. Identical residues are boxed. Abbreviations: AS, *Ascidia sydneiensis samea* (this study); B1, bovine brain-type isoform (Puopolo *et al.*, 1992); B2, bovine renal-type isoform (Nelson *et al.*, 1992); SC, budding yeast (Nelson *et al.*, 1989).

human and bovine. The ascidian subunit *B* isolated in this study is more closely related to the vertebrate homologs than the diverged isoform from bovine renal cells. So far, we have not found any evidence of other isoforms in this ascidian species.

On the one hand, it is difficult to explain the very low pH values observed in ascidian vacuoles by the action of V-ATPase alone because, in general, the maximum Δ pH that a V-ATPase can generate is around 4 pH units (Rea and Sanders, 1987). We have found that the extremely low pH of the vanadocyte vacuoles is partly explained by the release of protons with the hydrolysis of water molecules coordinated to

vanadium(III) ions (Kanamori *et al.*, unpublished data). However, it is still possible that the V-ATPase in the vanadocytes has an unusually tight coupling of ATPase activity and proton pumping and can generate such low pH values in the vacuole. Recently, the subunit composition of V-ATPase in the lemon juice sac, whose vacuole has a pH of 2.5, was reported to differ from that in other organs, and the authors suggested that it may be responsible for the low pH (Müller *et al.*, 1997). To determine whether V-ATPase actually functions in vanadocytes and how much proton-pumping activity the ascidian V-ATPase has, the subunit composition and the role of each subunit in vanadocytes must be clarified and will be our

future subjects of study.

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REFERENCES

- Finbow ME, Harrison MA (1997) The vacuolar H⁺-ATPase: a universal proton pump of eukaryotes. *Biochem J* 324: 697–712
- Forgac M (1989) Structure and function of vacuolar class of ATP-driven proton pumps. *Physiol Rev* 69: 765–796
- Forgac M (1992) Structure, function and regulation of the coated vesicle V-ATPase. *J Exp Biol* 172: 155–169
- Gimble FS, Thorner J (1992) Homing of a DNA endonuclease gene by meiotic gene conversion in *Saccharomyces cerevisiae*. *Nature* 357: 301–306
- Henze M (1911) Untersuchungen über das Blut der Ascidien. I. Mitteilung. Die Vanadiumverbindung der Blutkörperchen. *Hoppe-Seyler's Z Physiol Chem* 72: 494–501
- Henze M (1912) Untersuchungen über das Blut der Ascidien. II. Mitteilung. *Hoppe-Seyler's Z Physiol Chem* 79: 215–228
- Henze M (1913) Über das Vorkommen freier Schwefelsäure im Mantel von *Ascidia mentula*. *Hoppe-Seyler's Z Physiol Chem* 88: 345–346
- Henze M (1932) Über das Vanadiumchromogen des Ascidienblutes. *Hoppe-Seyler's Z Physiol Chem* 213: 125–135
- Hirata J, Michibata H (1991) Valency of vanadium in the vanadocytes of *Ascidia gemmata* separated by density-gradient centrifugation. *J Exp Zool* 257: 160–165
- Hirata R, Ohsumi Y, Nakano A, Kawasaki H, Suzuki K, Anraku Y (1990) Molecular structure of a gene, *VMA1*, encoding the catalytic subunit of H⁺-translocating adenosine triphosphatase from vacuolar membranes of *Saccharomyces cerevisiae*. *J Biol Chem* 265: 6726–6733
- Michibata H, Iwata Y, Hirata J (1991) Isolation of highly acidic and vanadium-containing blood cells from among several types of blood cell from Ascidiidae species by density-gradient centrifugation. *J Exp Zool* 257: 306–313
- Müller ML, Irkens-Kiesecker U, Kramer D, Taiz L (1997) Purification and reconstitution of the vacuolar H⁺-ATPases from lemon fruits and epicotyls. *J Biol Chem* 272: 12762–12770
- Nelson N (1992) The vacuolar H⁺-ATPase—one of the most fundamental ion pumps in nature. *J Exp Biol* 172: 19–27
- Nelson H, Mandiyan S, Nelson N (1989) A conserved gene encoding the 57-kDa subunit of the yeast vacuolar H⁺-ATPase. *J Biol Chem* 264: 1775–1778
- Nelson RD, Guo XL, Masood K, Brown D, Kalkbrenner M, Gluck S (1992) Selectively amplified expression of an isoform of the vacuolar H⁺-ATPase 56-kilodalton subunit in renal intercalated cells. *Proc Natl Acad Sci USA* 89: 3541–3545
- Puopolo K, Kumamoto C, Adachi I, Forgac M (1991) A single gene encodes the catalytic "A" subunit of the bovine vacuolar H⁺-ATPase. *J Biol Chem* 266: 24564–24572
- Puopolo K, Kumamoto C, Adachi I, Magner R, Forgac M (1992) Differential expression of the "B" subunit of the vacuolar H⁺-ATPase in bovine tissues. *J Biol Chem* 267: 3696–3706
- Rea PA, Sanders D (1987) Tonoplast energization: Two H⁺ pumps, one membrane. *Physiol Plantarum* 71: 131–141
- Saraste M, Sibbald PR, Wittinghofer A (1990) The P-loop—a common motif in ATP- and GTP-binding proteins. *Trends Biochem Sci* 15: 430–434
- Uyama T, Moriyama Y, Futai M, Michibata H (1994) Immunological detection of a vacuolar-type H⁺-ATPase in the vanadocytes of the ascidian *Ascidia sydneiensis samea*. *J Exp Zool* 270: 148–154
- Uyama T, Ueki T, Suhama Y, Kanamori K, Michibata H (1998) A 100-kDa antigen recognized by a newly prepared monoclonal antibody specific to the vanadocytes of the vanadium-rich ascidian, *Ascidia sydneiensis samea*, is glycogen phosphorylase. *Zool Sci* 15: 815–821.

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