

Increase in the ratio of heterotrophic to autotrophic microbes along the thermal gradients at Nakabusa hot springs

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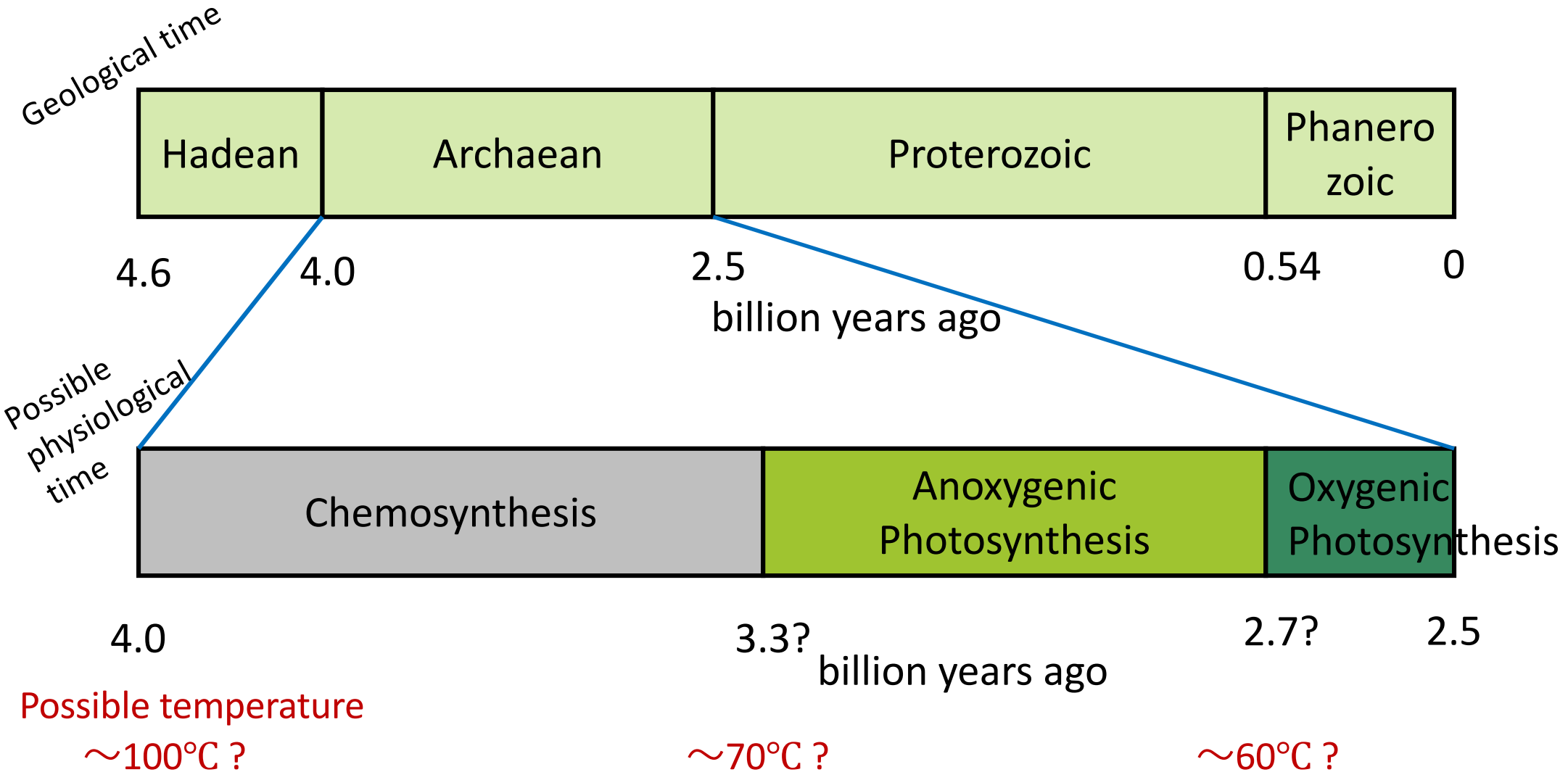
Outlines of the study

1. Evolution of microbial ecosystems in the Archaean was studied from the perspective of thermophilic communities in hot springs.
2. Communities based on chemosynthesis, anoxygenic photosynthesis, and oxygenic photosynthesis were analyzed along the thermal gradient.
3. The ratio of heterotrophic to autotrophic microbes was calculated in the communities with the different energy-producing mechanisms.

Geologic ages and possible major energy-producing mechanisms in Archaean



High-temperature zones and microbial communities in Nakabusa hot springs

Temperature: 90-45℃, Flow rate: 1200-0.1 mm/s,
Sulfide: 300-0 µmol/L, Oxygen: 500-25 µmol/L

90℃ 70℃ 62℃ 45℃

Chemosynthetic communities

Anoxygenic photosynthetic communities

Oxygenic photosynthetic communities

Two hot springs at Nakabusa with large temperature and physiological gradients

Kassen spring : 87°C at source : horizontal flow

86°C

66°C

56°C

Kojiki spring : 80°C at source : vertical flow

78°C

63°C

58°C

Methods

1. 32 diverse microbial communities were collected.
   (Temperature: 90℃-45℃, SH^-: 300–0 μmol/L, O_2: 500-25 μmol/L)

2. DNA was extracted and analyzed for the V4 region of 16S rRNA.

3. Three typical communities with different energy-producing mechansms were analyzed for the ratio of heterotrophic to autotrophic microbes.

Top 5 species-level variants in three communities with diverse producers

Chemosynthesis
87°C
SH^- : 238 µmol/L
O_2 : 25 µmol/L

nearest sp.	identity (%)	Phylum	Proportion
Thermocrinis ruber	96	*Aquificae*	71.1%
Caldimicrobium rimae	99	*Thermodesulfobacteria*	24.6%
Thermosphaera aggregans	97	*Crenarchaeota*	2.1%
Nitrososphaera viennensis	88	*Crenarchaeota*	0.6%
Thermosphaera aggregans	94	*Crenarchaeota*	0.5%

Anoxygenic Photosynthesis
68°C
SH^- : 202 µmol/L
O_2 : 33 µmol/L

Chloroflexus aggregans	100	*Chloroflexi*	28.5%
Caldimicrobium thiodismutans	100	*Thermodesulfobacteria*	15.5%
Rhodothermus profundi	87	*Bacteroidetes*	8.5%
Thermodesulfovibrio aggregans	96	*Nitrospirae*	4.8%
Thermobaculum terrenum	86	*Chloroflexi*	4.4%

Oxygenic Photosynthesis
55°C
SH^- : 8 µmol/L
O_2 : 470 µmol/L

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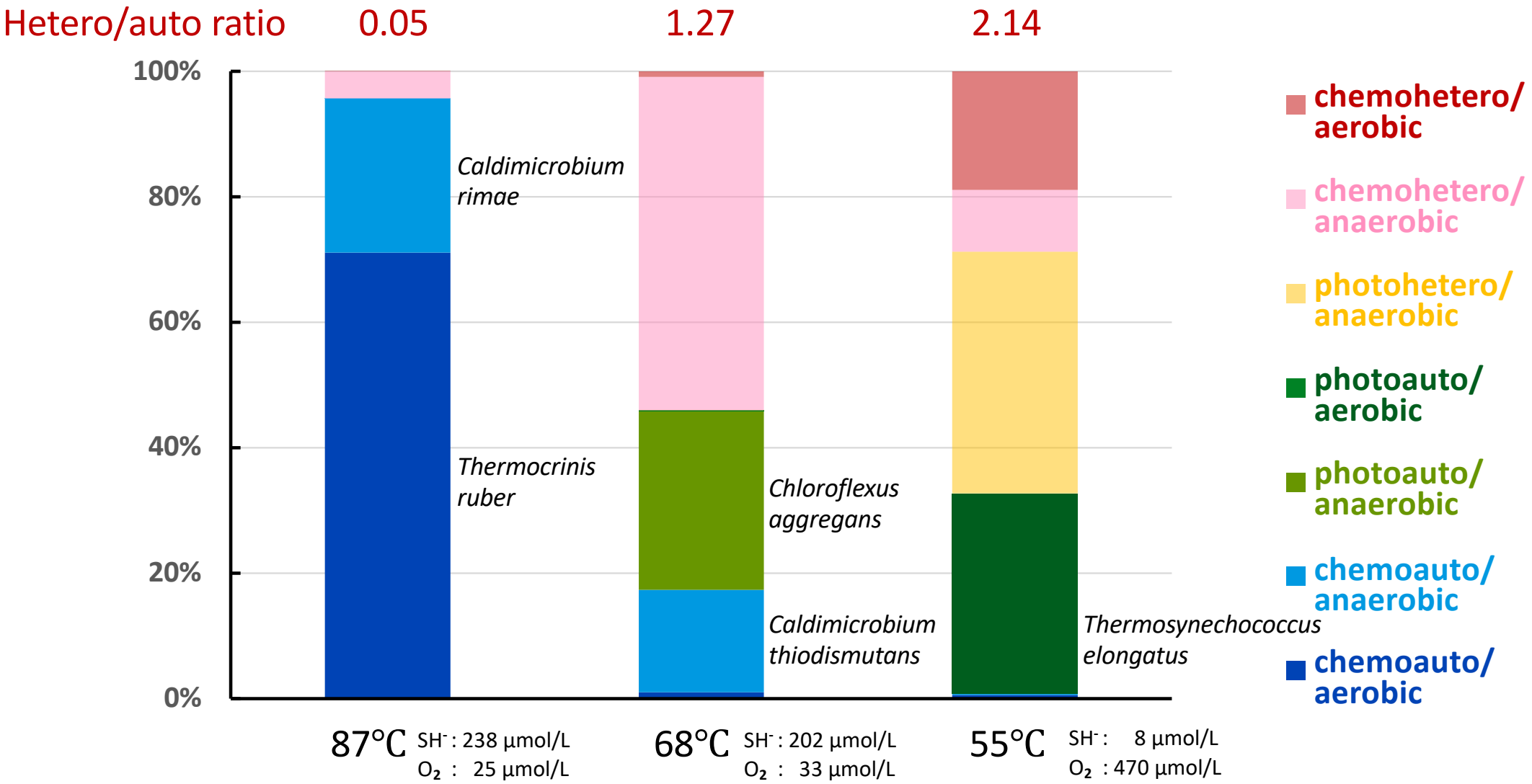
Thermosynechococcus elongatus	100	*Cyanobacteria*	31.8%
Roseiflexus castenholzii *	100	*Chloroflexi*	28.0%
Oscillochloris trichoides	92	*Chloroflexi*	8.1%
Stenotrophobacter roseus	88	*Acidobacteria*	3.8%
Leptolinea tardivitalis	88	*Chloroflexi*	3.0%

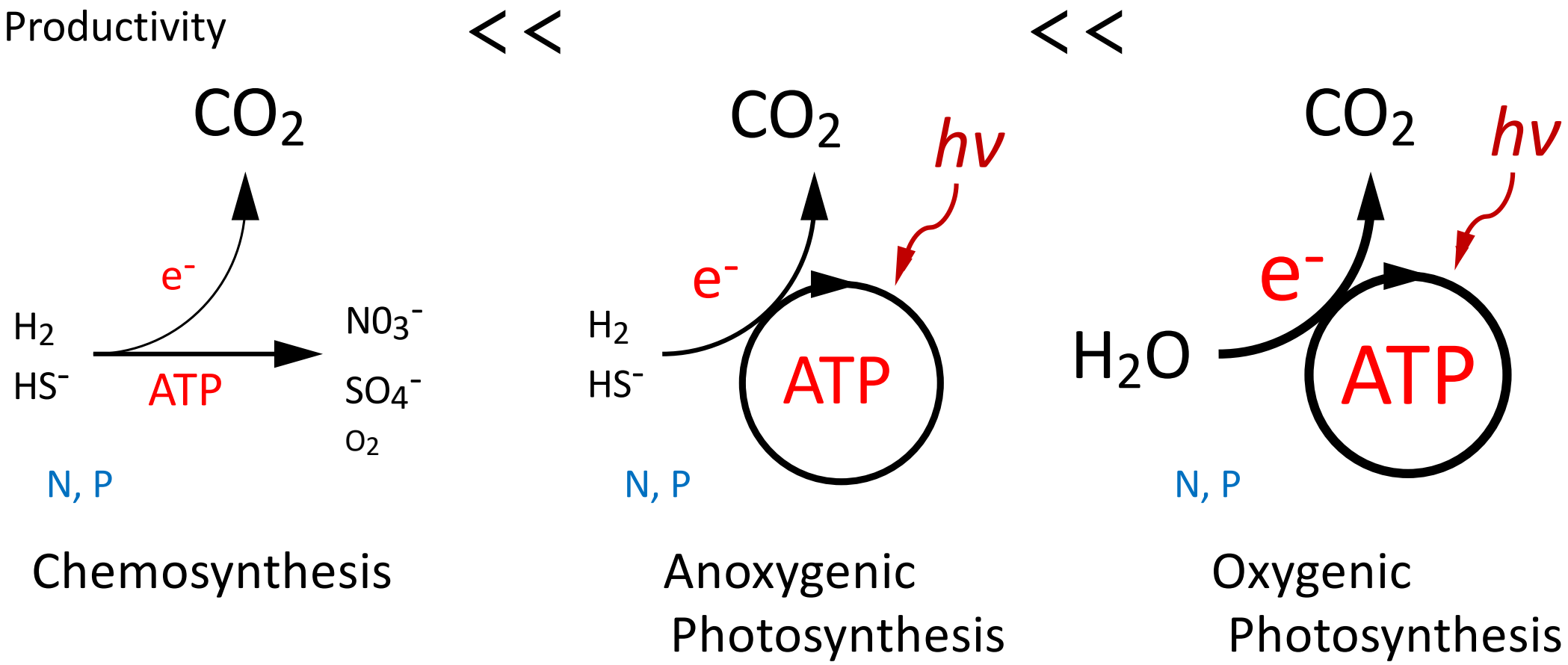
** A reddish photoheterotroph firstly isolated from Nakabusa hot springs.*

Autotrophic and heterotrophic microbes in the three communities



Energy-producing mechanisms and productivity

Productivity



Summary

1. Along the temperature gradient at Nakabusa hot springs, the ratio of heterotrophic to autotrophic microbes increased from 0.05 to 1.24 to 2.17 with decreasing temperature, representing the following transition of energy-production:

   chemosynthetic → anoxygenic photosynthetic → oxygenic photosynthetic metabolism.

2. A Similar increasing ratio of heterotrophs may have occurred in the course of the evolution of the ecosystem in Archean.

3. The increase may be related to the increase of productivity by the emergence of new autotrophic lifestyles.

Acknowledgments:
We appreciate Mr. Takahito Momose, the president of Nakabusa Onsen, for allowing us to use the hot springs. Field sampling and measurements were supported by Etsuko Matsuura and Mikako Kawai.

Phylum constitutions in the three communities