

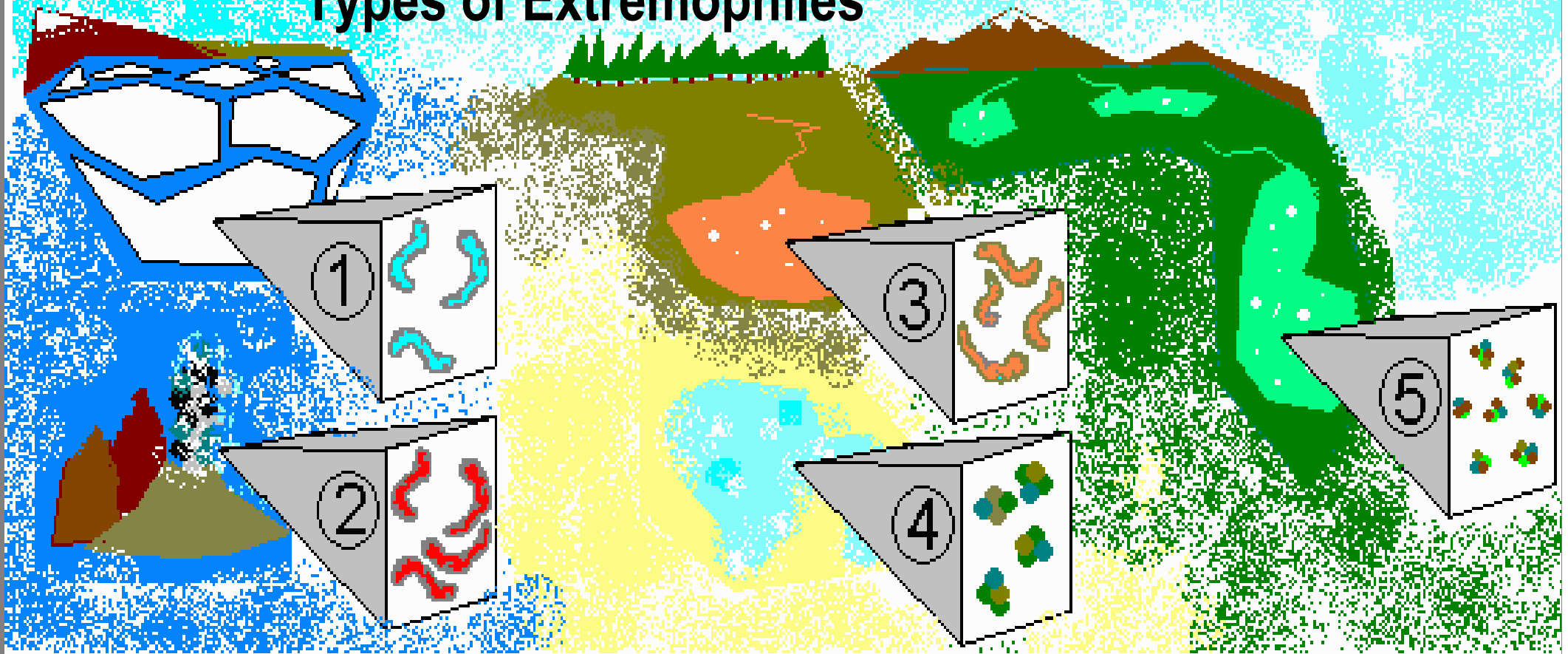
Subaerial and Extreme environments

Extremophiles are microorganisms— whether prokaryotes or eukaryotes — that survive under harsh environmental conditions that can include atypical temperature, pH, salinity, pressure, nutrient, oxic, water, and radiation levels

Survival in physical/chemical extremes:

- interior of cell is “normal”
- exocellular structures and enzymes protects the cell

Types of Extremophiles



1) Psychrophiles

Microbes that live in cold environments like sea ice and the arctic and antarctic ice packs.

2) Thermophiles

Microbes that live in very hot environments like deep sea vents and volcanic lakes.

3) Alkaliphiles

Microbes that live in basic environments like soda lakes.

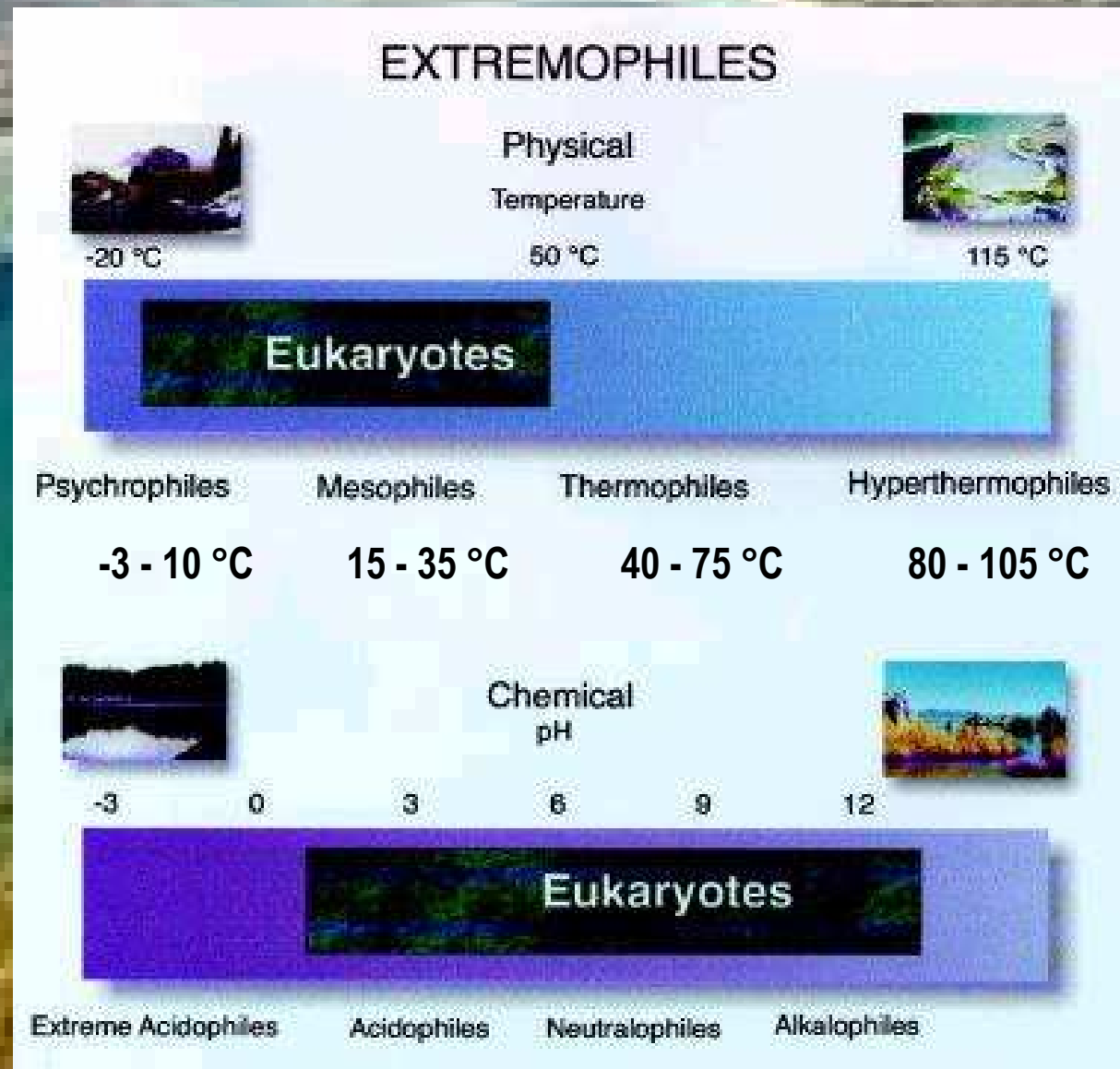
4) Halophiles

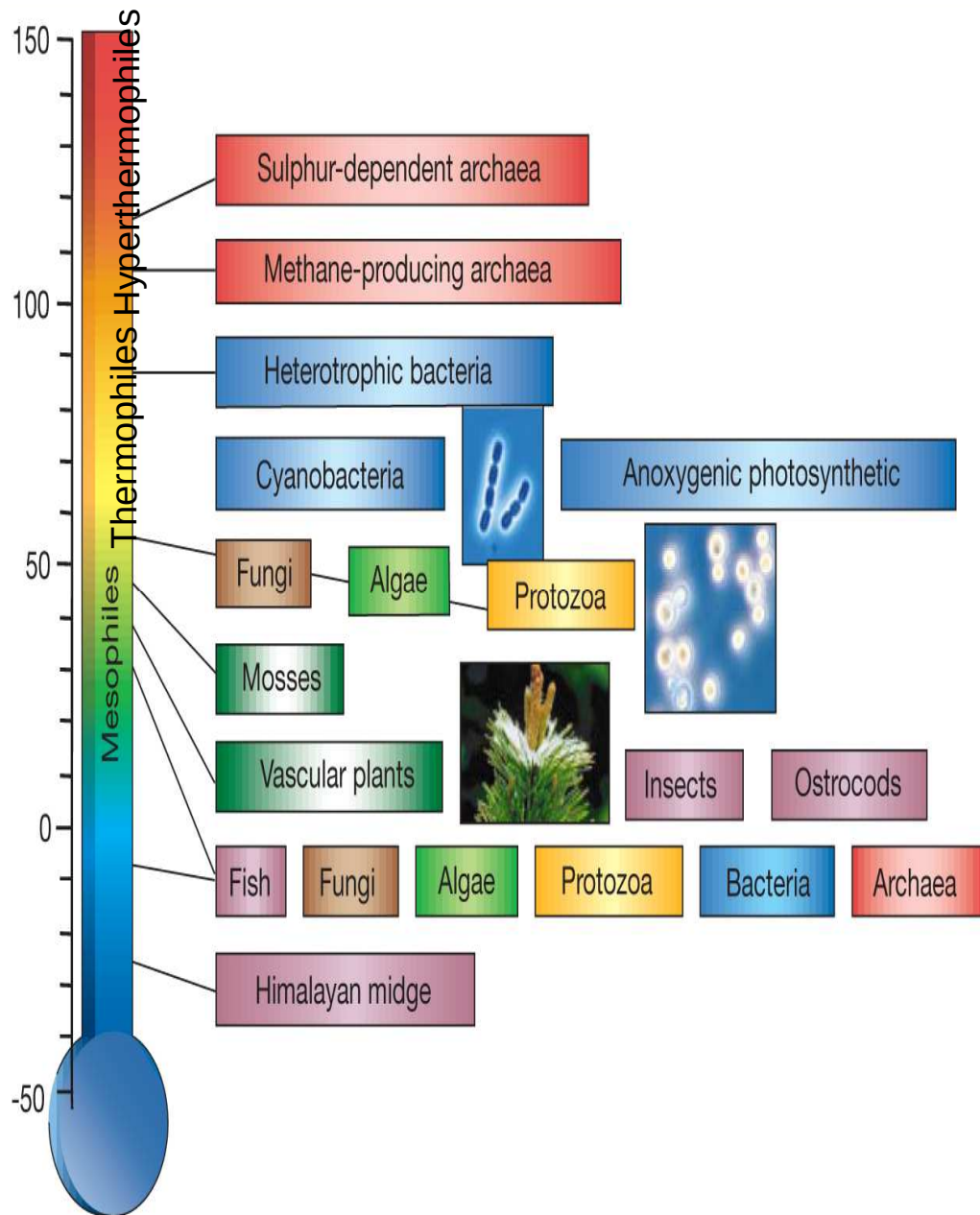
Microbes that live in very salty environments like salt lakes and salt mines.

5) Acidophiles

Microbes that live in acidic environments like sulphur springs.

Environmental Requirements





Thermal environments

Waters (geothermal)

Temperature
Salinity
pH

Cyano
Diatoms

Soils (sulphuric)

pH < 3.0
temperature
light
heavy metals

Rhodo-
(cyanidiaceae)
Chloro-
(Diatoms)
(Chryso-)
(Eugleno-)

Extreme environments
with stable conditions

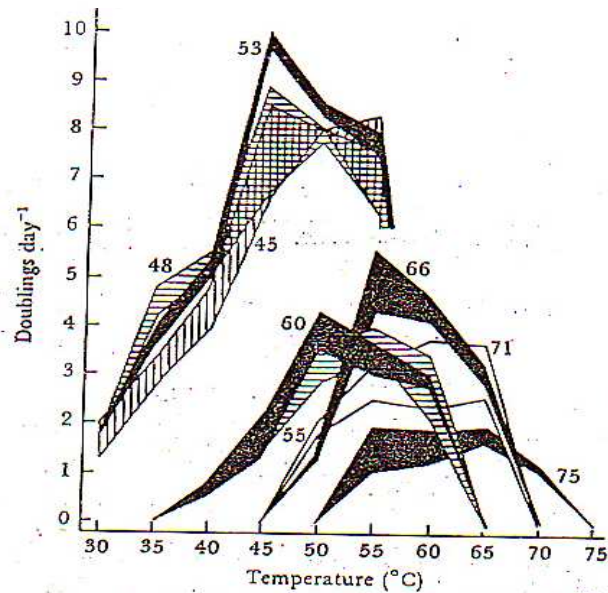
Sulphur Springs with Thermal and pH gradients

- cyanobacteria in hot water
- acidophilic/thermophilic microalgae on rocks and soil



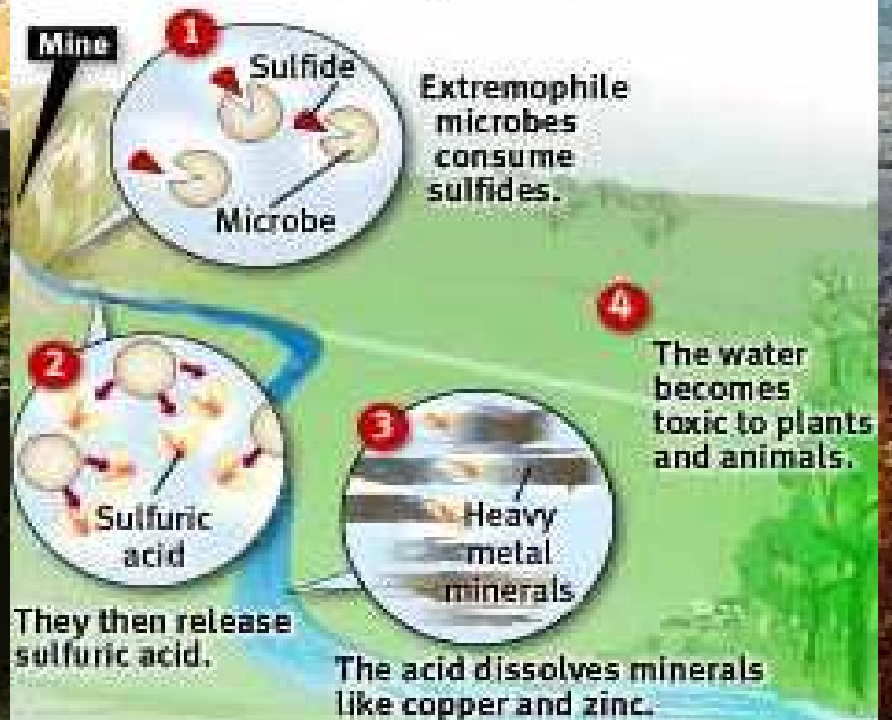
Yellowstone National park

Fig. 5.29 Growth rates of eight clones of thermophilic *Synechococcus* sp. at 5 °C intervals. Clones are classified into strains each characterised by different temperature optima, 45, 48 and 53, Strain I; 55 and 60, Strain II; 66 and 71, Strain III; 75, Strain IV. No clones have absolutely identical temperature optima.



Dangerous microbes

In the Iron Mountain Mine, scientists have discovered a microbe that is so hardy it can live in battery acid. This microbe consumes minerals and makes sulfuric acid, resulting in toxic water pollution.



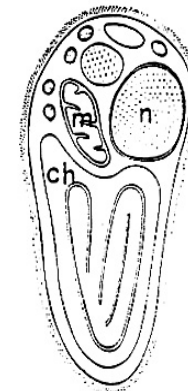
thermophilic / acidophilic microalgae



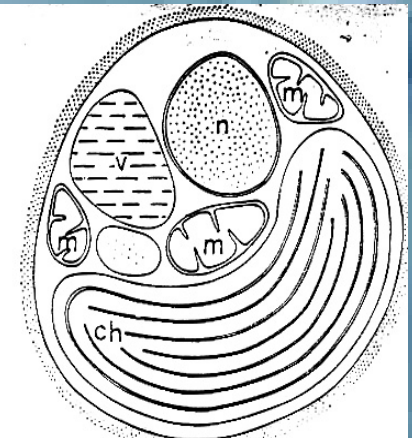
I "Cyanidi" Rhodophyta blu-verdi primitive



Cyanidium



Cyanidioschyzon



Galdieria

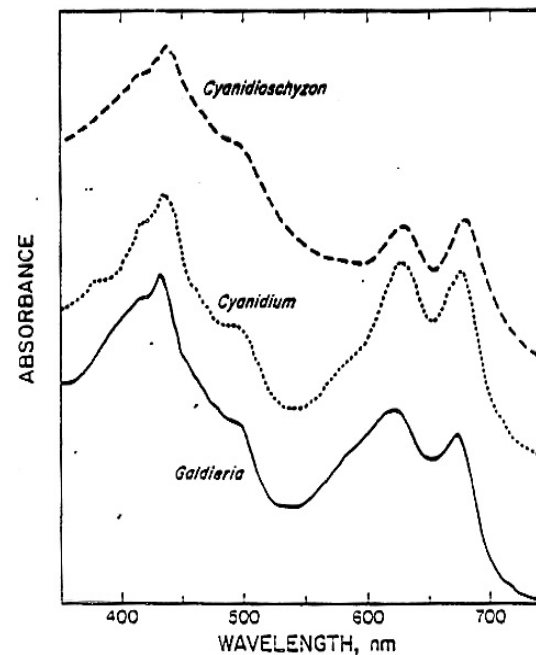


FIG. 1. The *in vivo* absorption spectra of three members of the Cyanidiophyceae. The peaks at the blue (436 nm) and red (674 nm) regions are of chlorophyll *a*, the "shoulder" at 488 nm is of carotenoid, and the peak at 626 nm is of the phycocyanin. The baseline for the different algae was shifted on the ordinate scale.

TABLE 1. Comparison of two acidothermophilic algae. Based on Fukuda and Nagashima (1987), Nagashima et al. (1987), and Seckbach et al. (1990). *Galdieria* is identified with the Allen strain (see text for details).

Feature	<i>Cyanidium caldarium</i> (forma A; RK-1)	<i>Galdieria sulphuraria</i> (forma B; M-8)
Cell morphology		
Shape	Spherical	Spherical
Size (μm)	2-6	9-11
Number of autospores	4	8, 16, and more
Ultrastructural aspects		
Chloroplast (Ct)	One	Several profiles
Ct shape	Spheric/cup	Multilobed
Plastid DNA form	Pod shape	Ring shape
Ct nucleoid region	Central	Peripheral
Ct-DNA aver. value (× 10 ⁴ photon)	72.9	230.3
Ratio Ct nucleoid/ nuclear DNA	0.38	1.25
Mitochondria	One	Several
Microbodies	Usually absent	Present
Vacuoles	Absent	Several
Activities and production		
Growth	Oblig. autotroph	Auto-+hetero- troph
NH ₄ uptake	Yes	Yes
NO ₃ uptake	Yes	No
NaCl tolerance (%)	3-4	10
Trienoic acids	No	Yes
Storage glucar.	Phytoglycogen	Amylopectin

High concentration of Heavy Metals

Italian Sulphuric acid environments (Albertano, 1995)

	number of samples ^a	lowest pH in nature ^b	T (°C) in nature ^c	lowest pH recorded ^d
Rhodophyta				
<i>Cyanidioschyzon merolae</i>	5 (11)	1.5	35	
<i>Cyanidium caldarium</i>	28 (35)	1.0	36	0.05 (Brock 1978)
<i>Galdieria sulphuraria</i>	58 (70)	0.8	38	
Chrysophyta				
<i>Ochromonas</i> sp.	2	2.8	23	1.0 (Gromov <i>et al.</i> 1989)
Bacillariophyta				
<i>Pinnularia</i> sp.	53	1.5		1.7 (Negoro 1944)
Chlorophyta				
<i>Dunaliella acidophila</i>	2 (5)	0.8	23	1.5 (Kalina 1965)
<i>Chlamydomonas</i> sp.	27 (29)	2.8		1.7 (Negoro 1944)
<i>Chlorella saccharophila</i>				
var. <i>saccharophila</i>	24 (39)	2.5	26	
<i>C. saccharophila</i>				
var. <i>ellipsoides</i>	30 (36)	1.2	26	{ 1.0 (Brock 1978) 0.9 (Whitton & Diaz 1981)
<i>C. protothecoides</i>				
var. <i>acidicola</i>	23 (35)	0.9	27	
<i>Pseudococcomyxa simplex</i>	33 (58)	1.5	30	3.5 (Desortova 1974)
<i>Stichococcus bacillaris</i>	54 (75)	1.5	29	0.9 (Whitton & Diaz 1981)
<i>Viridiella fridericiana</i>	4	1.8	28	
Euglenophyta				
<i>Euglena mutabilis</i>	1 (4)	3.0		1.0 (Negoro 1944)

- a The number is referred to the sites where the alga formed conspicuous populations; in brackets the number of samples in which the alga was observed in enrichment cultures. Based on Pinto and Taddei (1977).
b The lowest pH at which the alga was observed in nature in Italy.
c The highest temperature at which the alga was found in nature.
d The lowest pH value reported in literature for the alga. References are in brackets.

Table 2. Inhibitory concentrations of heavy metals on strain of acidophilic algae isolated from Italian sulphuric environments. The values (n) indicate the lethal concentrations to 50% of inoculum (LC₅₀)*.

	pH ^a	Copper (CuCl ₂)	Mercury (HgCl ₂)
Rhodophyta			
<i>Cyanidioschyzon merolae</i>	1.5	16	1.4
<i>Cyanidium caldarium</i>	1.5	8	1.7
<i>Galdieria sulphuraria</i>	1.5	21	4.0
Chlorophyta			
<i>Dunaliella acidophila</i>	1.0	0.1	0.5
<i>Chlorella saccharophila</i> ^b	3.0	15 ^c	0.3
<i>C. protothecoides</i> var. <i>acidicola</i>	3.0	31 ^c	2.0 ^c
<i>Stichococcus bacillaris</i>	3.0	64 ^c	0.2
<i>Viridiella fridericiana</i>	3.0	32	0.2

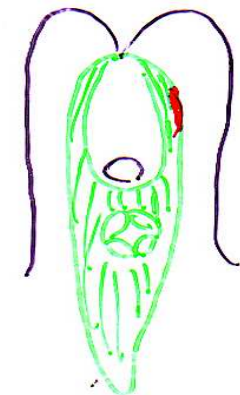
* Based on Albertano *et al.* 1979, 1980; Aliotta and Pollio 1982; Aliotta *et al.* 1986; Albertano and Pinto 1986.

a The pH values at which the LC₅₀ was determined.

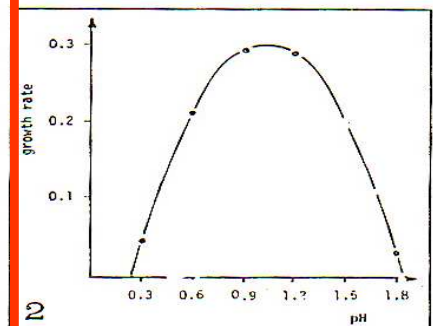
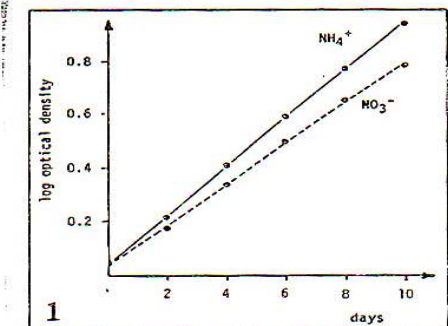
b Strain 211-9a G6 from the CCAP, Cambridge

c The toxicity of elements resulted several fold increased at pH 6.5 (Aliotti 1983).

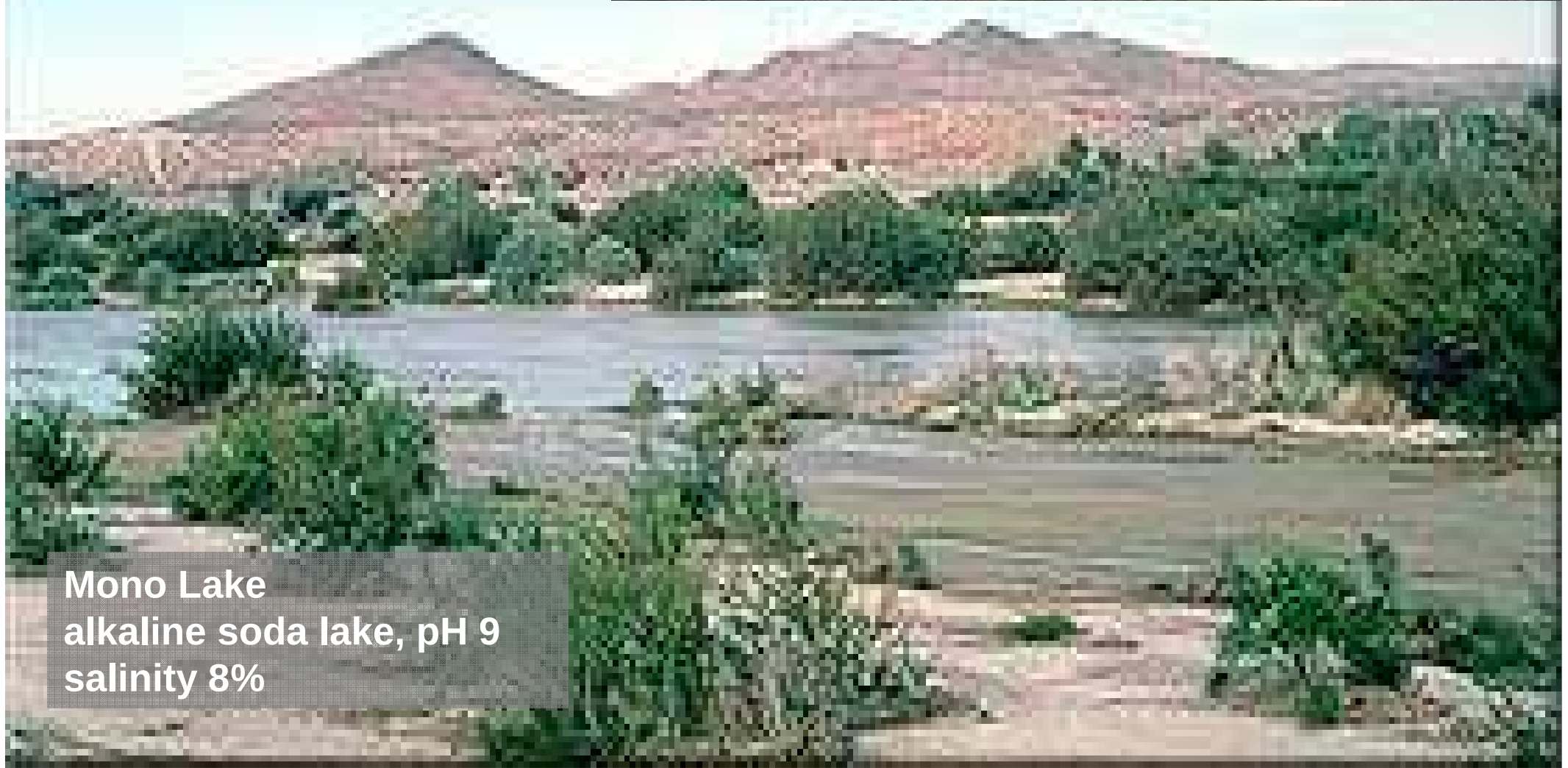
The most acidophilic



Dunaliella acidophila



Alkalophilic cyanobacteria
Soda lakes in Africa and
western U.S (pH 9-12)



Mono Lake
alkaline soda lake, pH 9
salinity 8%

Psychrophilic algae

Low temperature habitats:

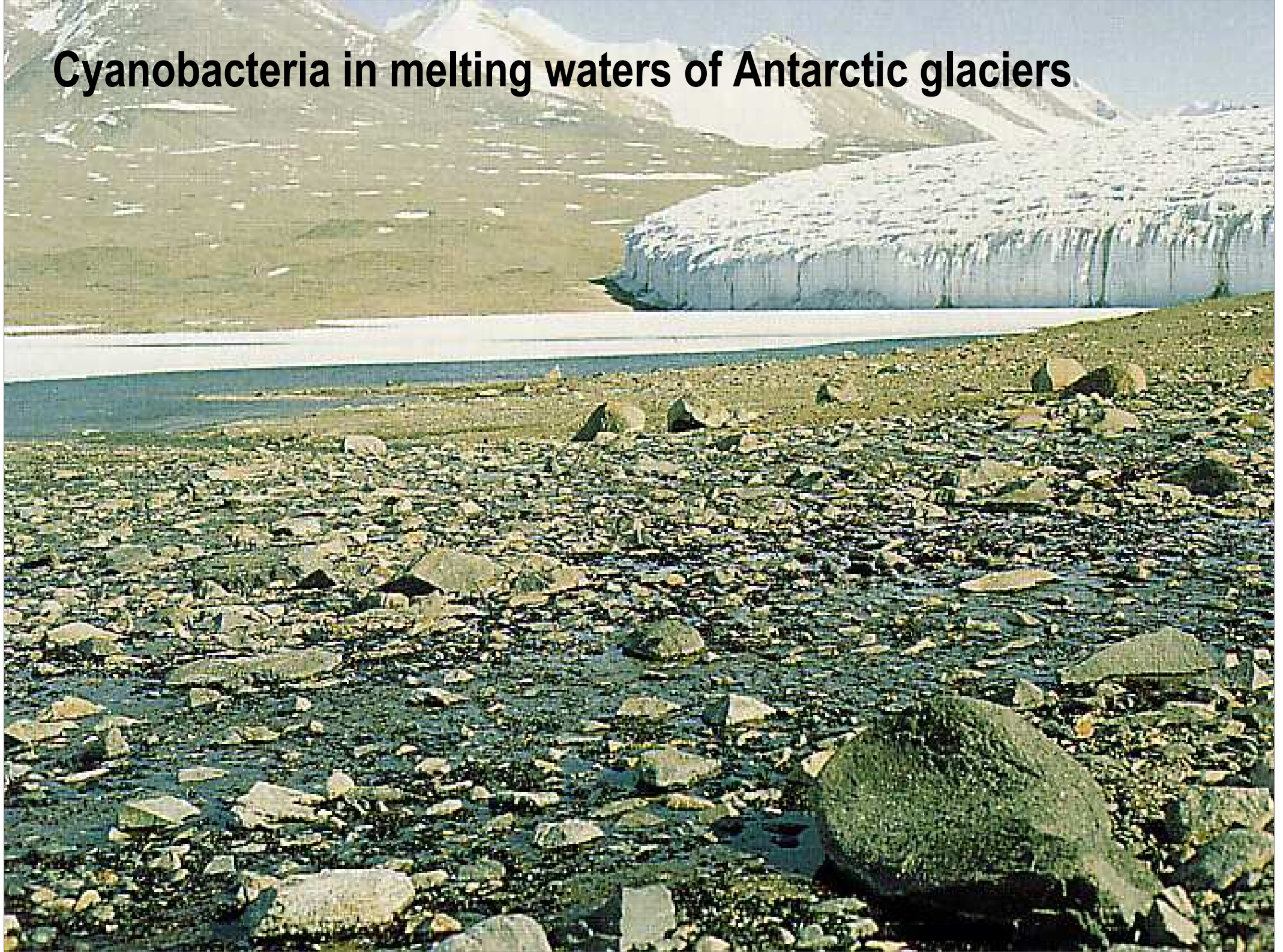
- snow, ice
- Arctic and Antarctic
- Oceans and Deep sea (1-4 °C)

- proteins rich in α -helices and polar groups which allow for greater flexibility
- “antifreeze proteins” that maintain liquid intracellular conditions by lowering freezing points of other biomolecules
- membranes that are more fluid, containing unsaturated *cis*-fatty acids which help to prevent freezing
- active transport at lower temperatures

Some microorganisms thrive in temperatures well below the freezing point of water, such as in Antarctica

Some researchers believe that psychrophiles live in conditions mirroring those found on Mars

Cyanobacteria in melting waters of Antarctic glaciers



Factors affecting ice algae growth



Ice algal community

Temperature

- Temperatures can reach – 20 C
- Form stress resistant cysts at specific stages in their life cycle
- Maintenance of functional lipid membranes that regulates membrane fluidity

Light Availability

- Must adapt to low-light conditions
- Have high photosynthetic efficiencies
- Concentrated accessory pigment fucoxanthin

Ice Marine Algae

Low Temperature
Low Irradiance
High salinity

• Arctic

• Antarctic

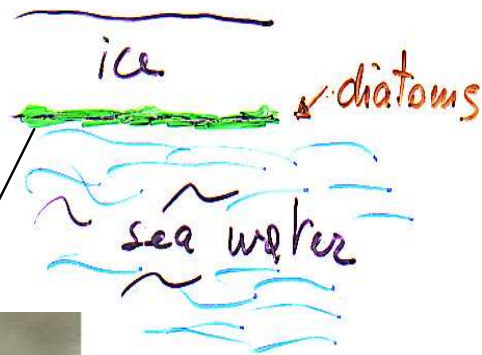
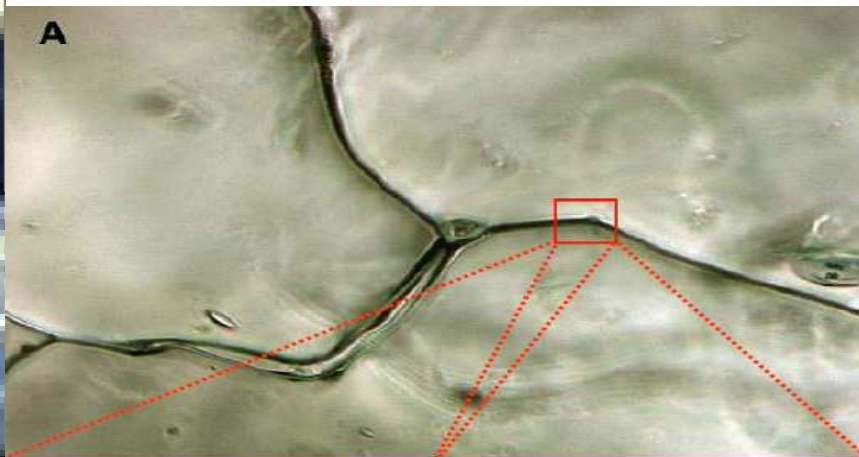


Table 5.11. Species recorded from the Antarctic sea ice, (Bunt & Wood, 1963) and from the Arctic sea ice (Meguro, Ito & Fukushima, 1966)

Antarctic species	Arctic species
<i>Amphiprora kjellmanii</i>	<i>Amphiprora kryophila</i>
<i>A. oestrupii</i>	<i>Gomphonema exigium</i> v. <i>arctica</i>
<i>Biddulphia weisflogii</i>	<i>Navicula algida</i>
<i>Coscinodiscus subtilis</i>	<i>N. crucigeroides</i>
<i>Eucampia balaustium</i>	<i>N. directa</i>
<i>Fragilaria linearis</i>	<i>N. gracilis</i> v. <i>inaequalis</i>
<i>Nitzschia martiana</i>	<i>N. kjellmanii</i>
<i>N. seriata</i>	<i>N. obtusa</i>
<i>Pleurosigma antarcticum</i>	<i>N. transitans</i> and v. <i>derasa, erosa</i>
<i>Rhizosolenia alata</i>	<i>N. trigocephala</i>
<i>R. rostrata</i>	<i>N. valida</i>
	<i>Nitzschia lavuensis</i>
	<i>Pinnularia quadratarea</i> and v. <i>biconstricta, capitata, stuxbergii</i>
	<i>P. semiinflata</i> and v. <i>decipiens</i>
	<i>Pleurosigma stuxbergii</i> and v. <i>rhomboides</i>
	<i>Stenoneis inconspicua</i>

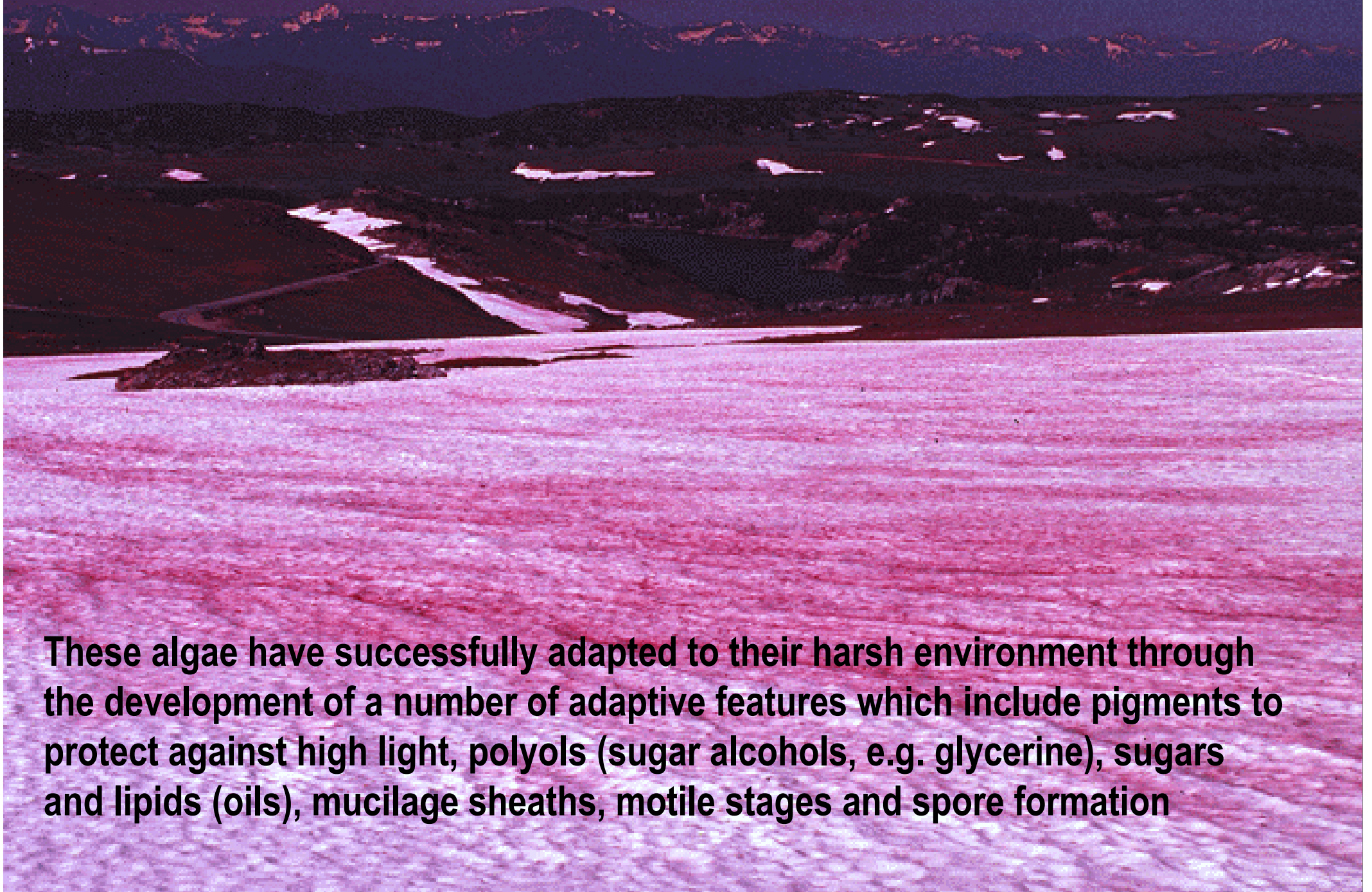
Endemic species



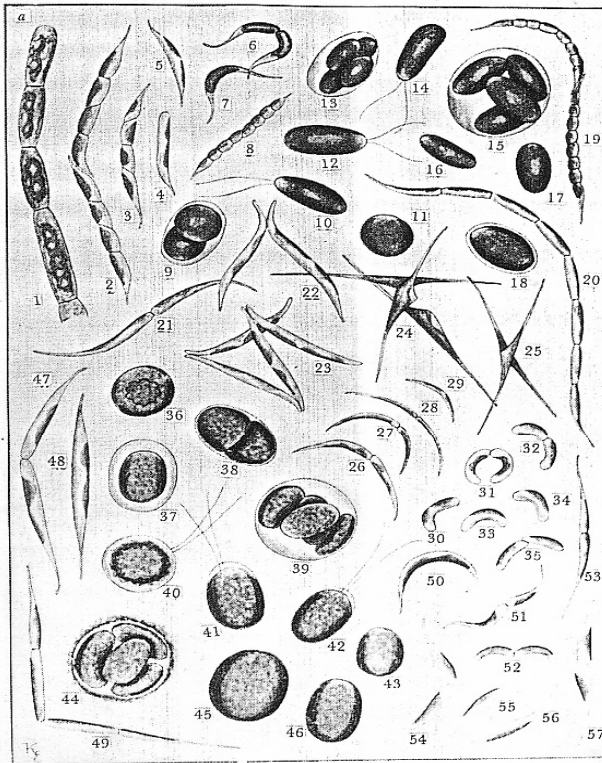
10 µm

10 µm

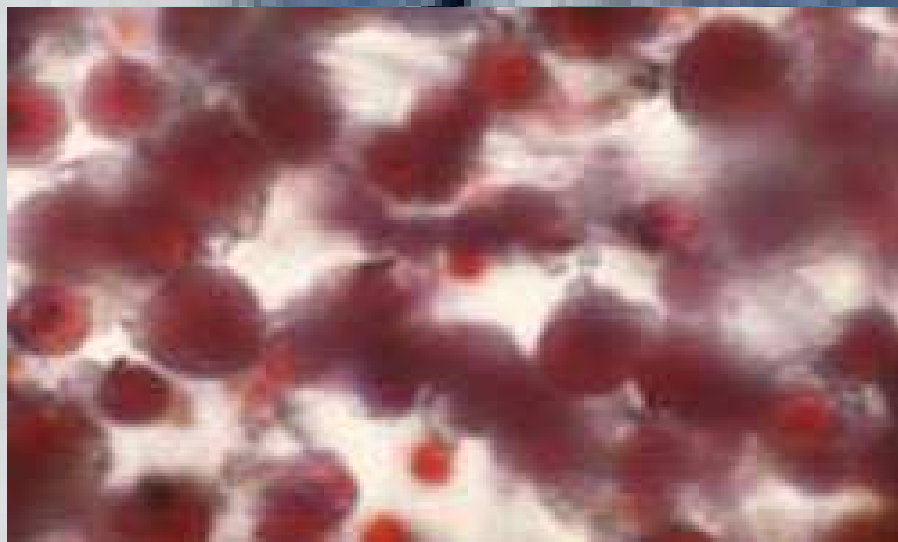
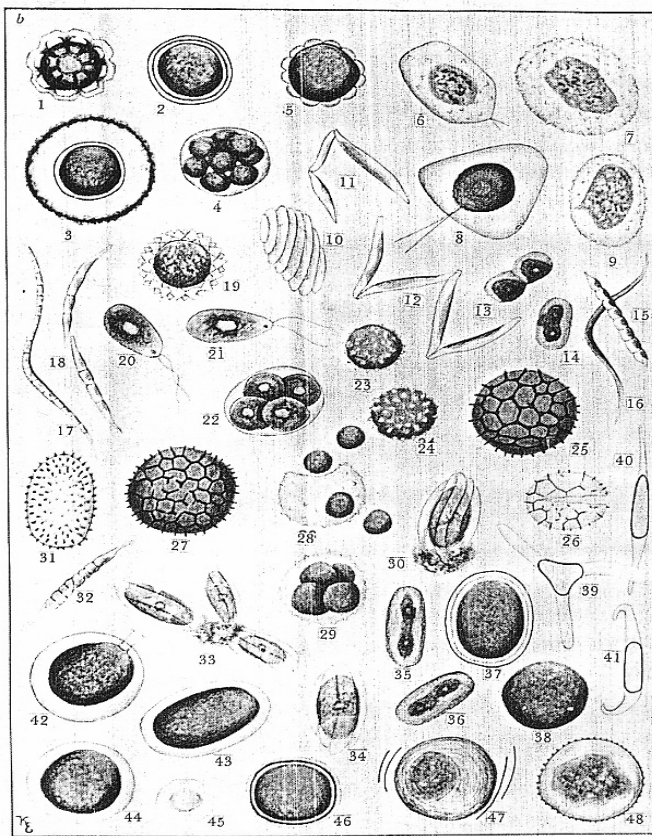
SNOW ALGAE and CYANOBACTERIA



These algae have successfully adapted to their harsh environment through the development of a number of adaptive features which include pigments to protect against high light, polyols (sugar alcohols, e.g. glycerine), sugars and lipids (oils), mucilage sheaths, motile stages and spore formation



Snow algae



Snow Algae (*Chlamydomonas nivalis*)



A bloom of *Chloromonas rubroleosa* in Antarctica

Snow Algae

Low Temperature
High Irradiance
Low Nutrients

- Green snow (*Carteria*, etc.)
- Red snow (*Chlamydomonas nivalis*, etc.)

- optimum growth $< 10^{\circ}\text{C}$

- germination at soil-snow interface

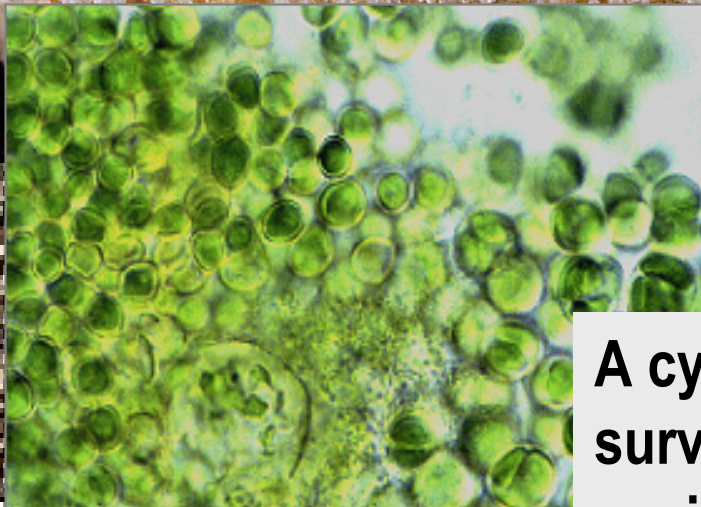


Table 5.10. The species which occur in surface snows of different colours from sites in the South Orkney Islands. Red spores include those from *Chlamydomonas nivalis* and *Chlorosphaera antarctica* and numbers for these species are for green cells only. From Fogg 1967

Species	Cell no./mm ³ surface snows					
	Green snow, 30. i. 66, Meier Point, Coronation Island	Green snow, 13. ii. 66, Moraine Valley, Signy Island	Yellow snow, 4. ii. 66, Factory Cove, Signy Island	Yellow snow, 12. ii. 66, Moraine Valley, Signy Island	Red snow, 14. ii. 66, Moraine Valley, Signy Island	Red snow, 4. ii. 66, Factory Cove, Signy Island
<i>Chlamydomonas nivalis</i>	955	0	0	0	0	0
<i>Chlorosphaera antarctica</i>	15	0	0	1	3	0
Red spores	0	0	0	0	40	45
<i>Raphidonema nivale</i>	115	4770	364	289	2	320
<i>Hormidium subtile</i> ^a	768	0	0	0	0	0
<i>Trochiscia antarctica</i>	2	0	0	0	0	0
<i>Chodatella brevispina</i>	0	12	0	0	1	10
<i>Scotiella antarctica</i>	0	0	33	3	0	55
<i>Ochromonas</i> (?) sp.	32	12	2620	3	1	4170

Crypto- and chasmoendolithic *Chroococcidiopsis*

Low water
Very high or low temperature



A cyanobacterium which can survive in very harsh environments, such as hot, arid deserts throughout the world, and in the frigid Ross Desert in Antarctica



AMBIENTI SUBAEREI SUOLO, ROCCE, PIETRE, ALBERI, EDIFICI

Cianobatteri, Diatomee, Alghe verdi, Xantophyceae

epilitici ed endolitici (sopralitorale, grotte, deserti caldi e freddi)

epifiti di piante

simbionti di piante e animali

FATTORI AMBIENTALI

- UMIDITA'
- pH
- LUCE
- TEMPERATURA
- DISPONIBILITA' DI NUTRIENTI

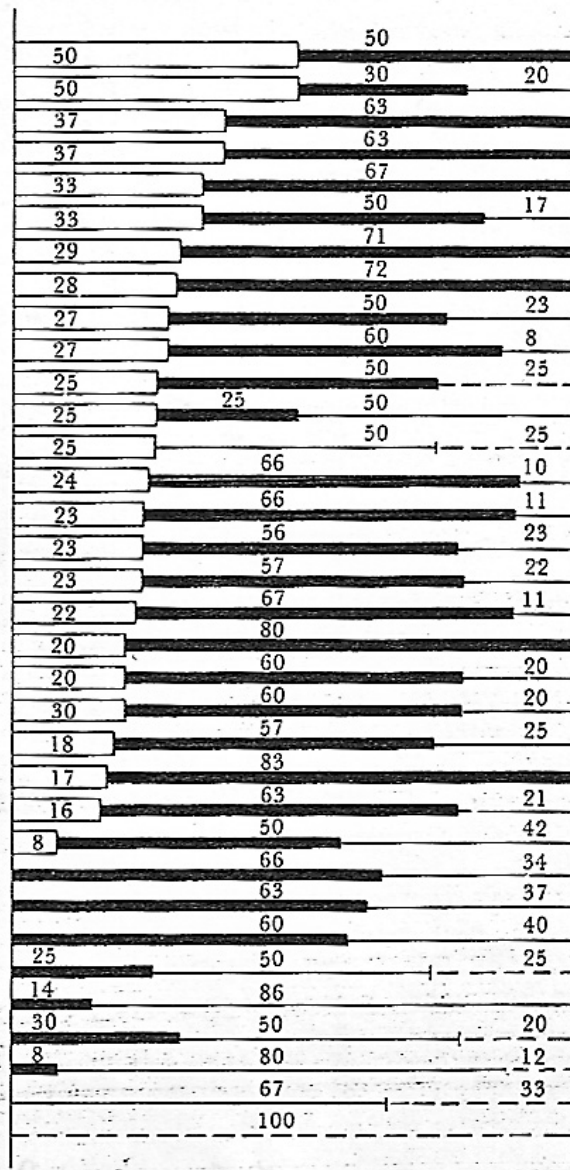
Ruolo dei cianobatteri nell'ecosistema del suolo

- Input di carbonio - fotosintesi
- Input di azoto – azotofissazione
- prevengono l'erosione del suolo
- trattengono acqua

Soil diatoms

Number of species of soil diatoms in four pH ranges. White columns, pH 8.1-7.0; thick black lines, pH 6.9-6.0; thin black lines, pH 5.9-5.0, and dotted lines, pH 4.9-3.7. From Brendemuhl, 1949.

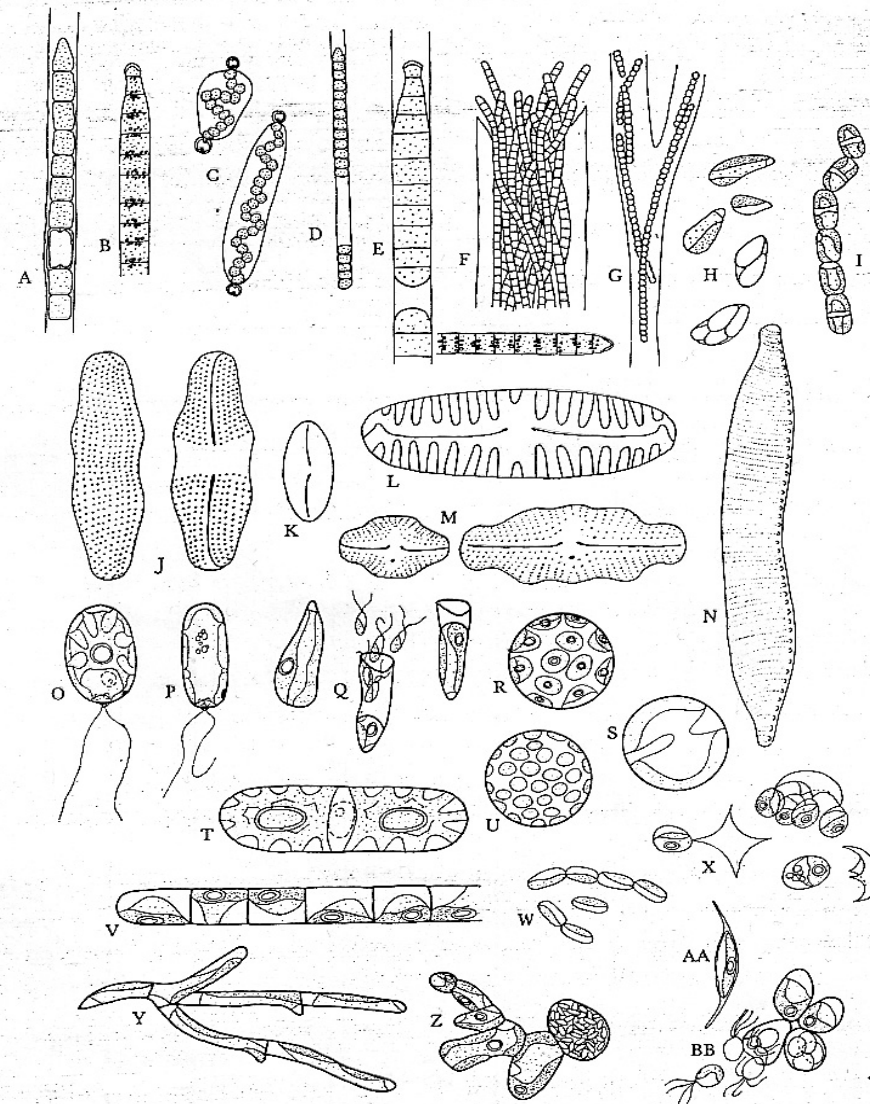
Achnanthes coarctata
Navicula cincta var. *Heufleri*
N. atomus
N. caduca
N. mutica var. *nivalis*
Surirella ovata
Navicula mutica var. *ventricosa*
Amphora montana
Achnanthes lanceolata
Navicula mutica
Achnanthes minutissima
Gomphonema parvulum
Pinnularia viridis
Hantzschia amphioxys
Stauroneis anceps
Nitzschia palea
Pinnularia obscura
Navicula cryptocephala
N. gibbula
Nitzschia amphibia
Stauroneis montana var. *lanceolata*
Pinnularia borealis
Nitzschia debilis
Navicula contenta f. *biceps*
N. minima
N. insociabilis
N. brekkaensis
Stauroneis montana
Navicula fossalis
Frustulia vulgaris
Pinnularia microstauron f. *diminuata*
P. subcapitata
Eunotia tenella
Pinnularia irrorata



Soil cyanobacteria and algae

Fig. 5.27. Some microscopic terrestrial algae found on mineral soils or brown earths below the grass *Deschampsia antarctica* on Signy Island. A, *Nodularia*; B, *Oscillatoria*; C, *Nostoc*; D, *Phormidium*; E, *Phormidium*; F, *Microcoleus*; G, *Schizothrix*; H, *Monodus*; I, *Heterothrix*; J, *Achnanthes*; K, *Navicula*; L, *Pinnularia*; M,

Navicula; N, *Hantzschia*; O, *Chlamydomonas*; Q, *Rhopalocystis*; R, *Planktoniella*; S, *Myrmecia*; T, *Cylindrocapsa*; U, *Bracteolobos*; V, *Chlorohormidium*; W, *Stichococcus*; X, *Dicellastrum*; Y, *Microthamnium*; Z, *Gongosira*; AA, *Planorbulina*; BB, *Planophila*.

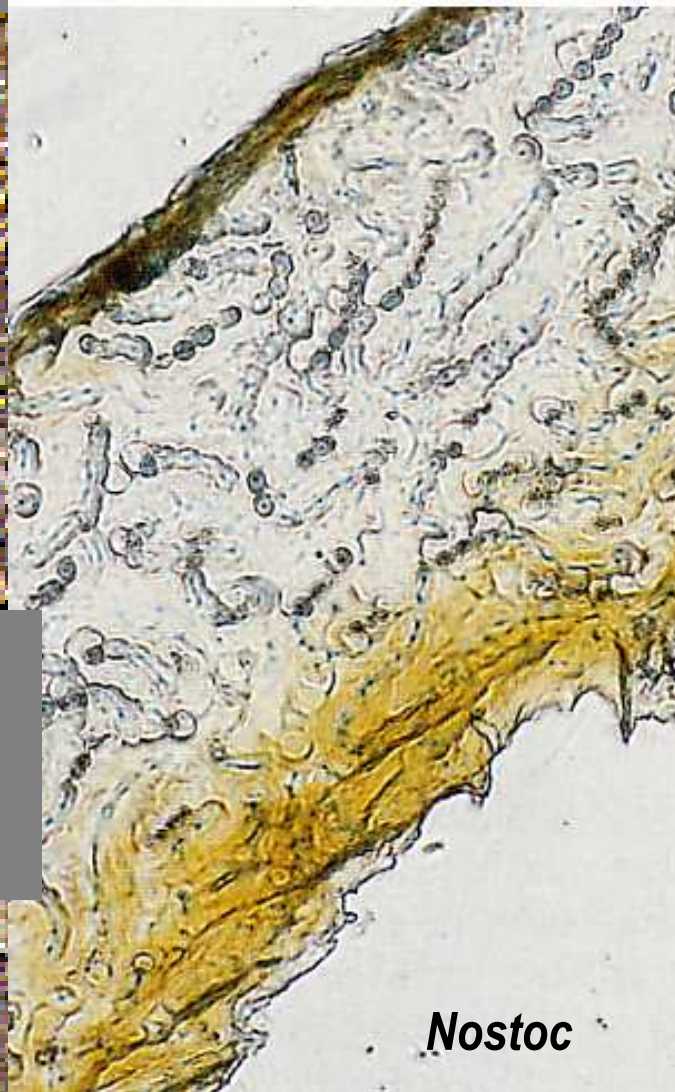


Soil cyanobacteria

- **mucillagine (EPS)** formata fino al 90% da polisaccaridi

- **composti che filtrano la radiazione UV** e evitano il danno al DNA nella mucillagine giallo-marrone e/o nel citoplasma

- **azotofissatori (N_2)**
alcuni hanno cellule specializzate, le **eterocisti**



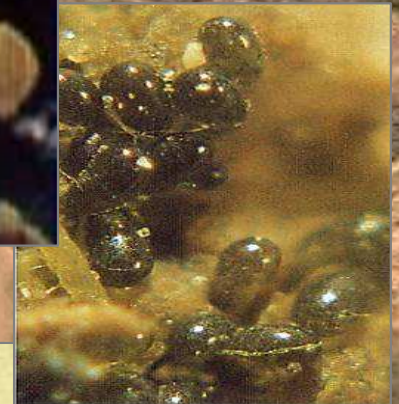
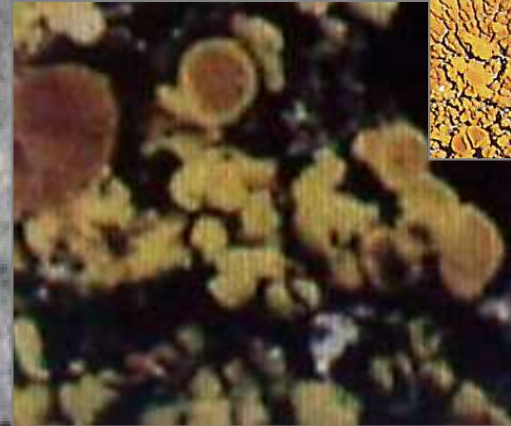
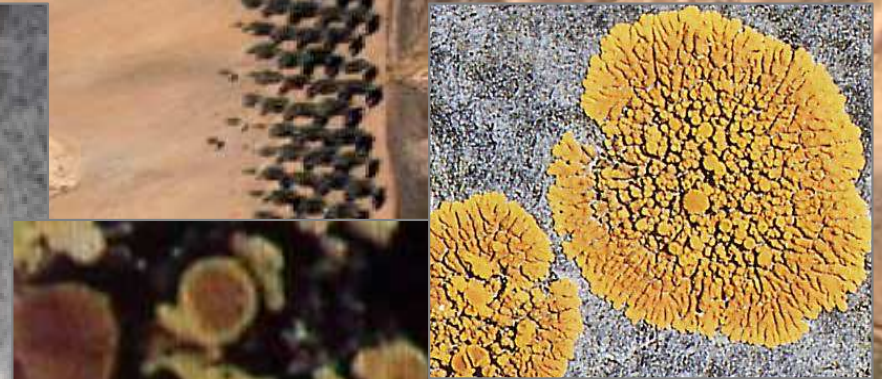
Epilithic aerophytic cyanobacteria



Cianobatteri del suolo: apporto di nuovo carbonio e azoto ($1-10 \text{ kg ha}^{-1} \text{ y}^{-1}$ nei deserti)



Nostoc



Simbionti nei *licheni*, in *Geosiphon* e *Blasia*

Cianobatteri resistenti al disseccamento: specie tipiche di suoli aridi e semi-aridi

Europa (Alpi, Artico, Grecia, Spagna)

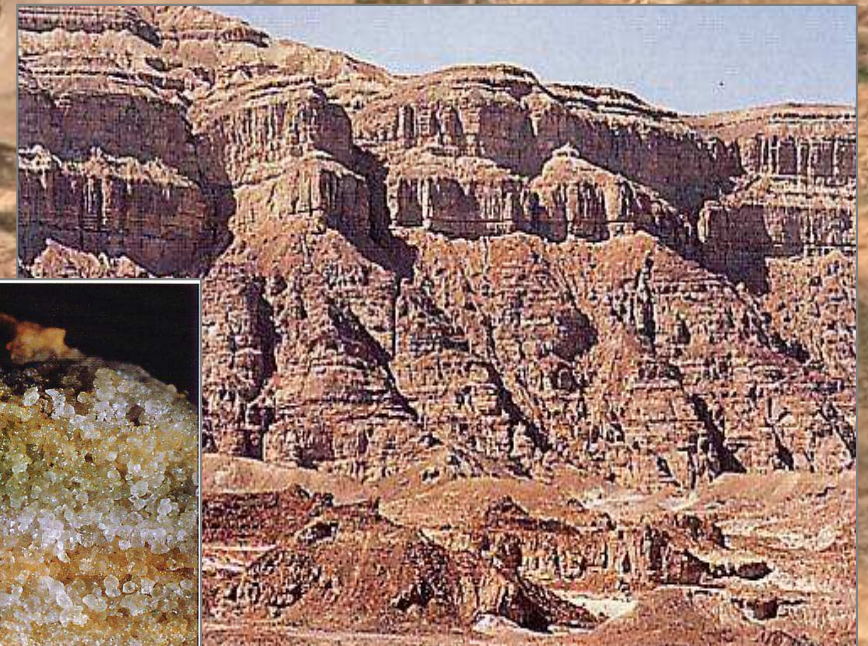
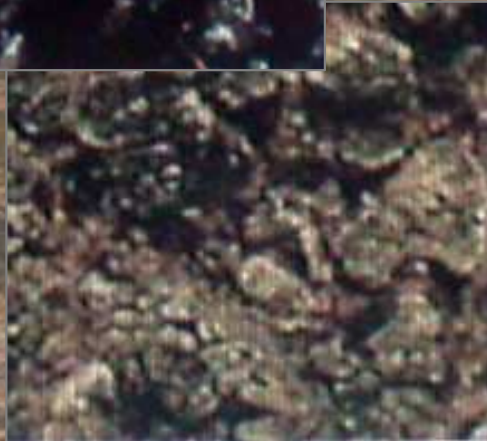
Africa

Asia (Medio Oriente, Cina, India)

Nord America,

Sud America (Argentina, Brasile, Cile, Venezuela)

Australia



formano croste

“lisce” o “rugose”

nello strato
superficiale del suolo

da 0.5 - 4.0 mm

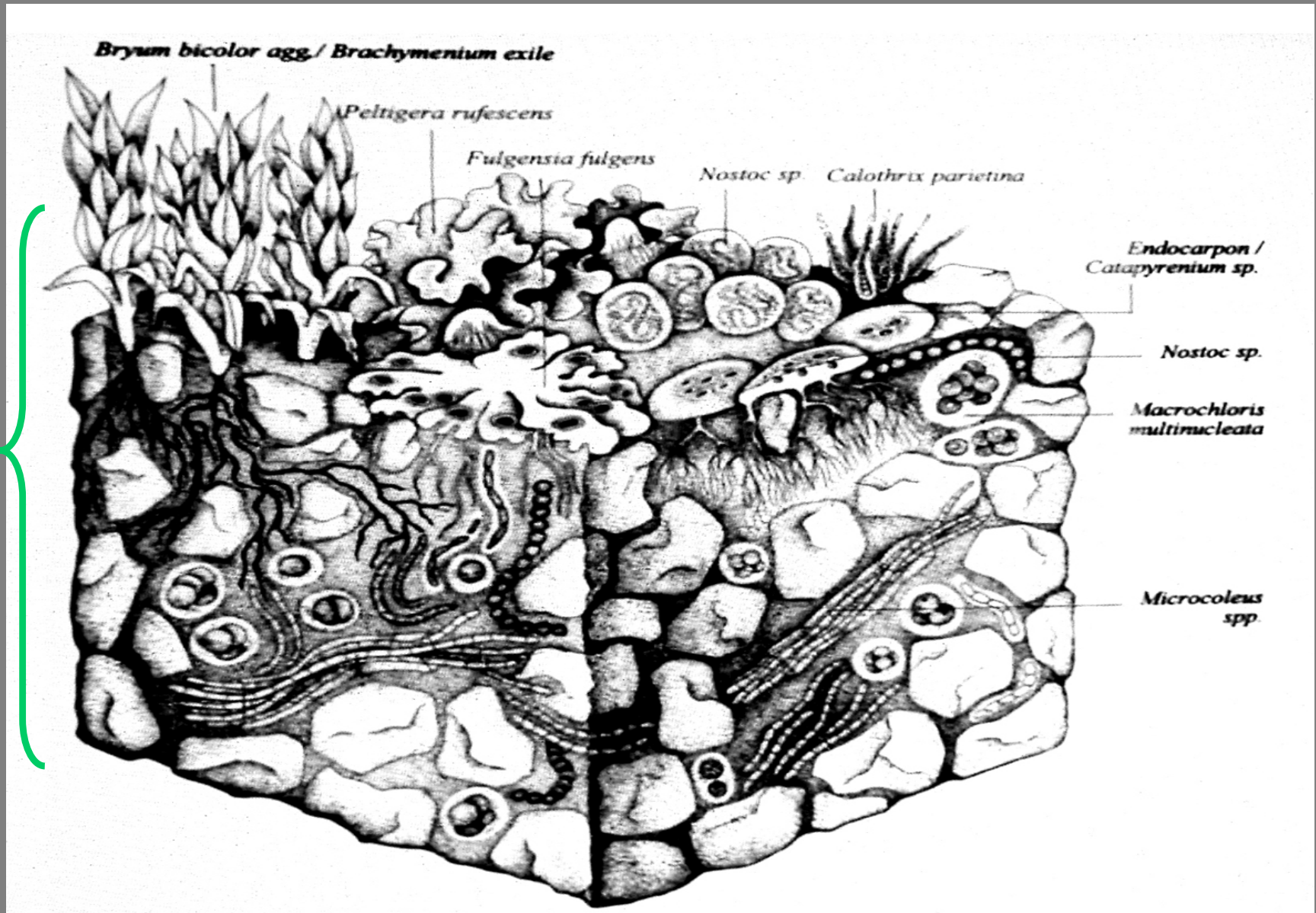


Chroococcidiopsis nei deserti caldi e freddi (Billi and Potts, 2002; Potts, 1999)

I Cianobatteri sono una componente dominante delle “BSC - biological soil crusts” (spessore ~ 3 mm)

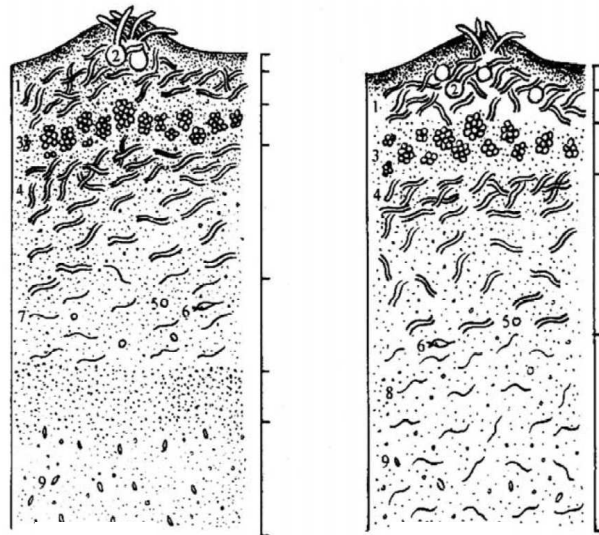
licheni
muschi

alghe verdi
diatomee
epatiche
+
batteri
funghi



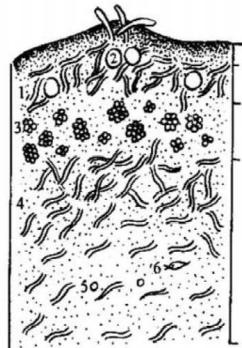
(modificato da Belnap 2003)

BSC: distribuzione verticale nel suolo e ruolo degli EPS contro erosione e perdita d'acqua

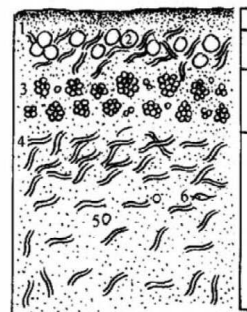


42 anni

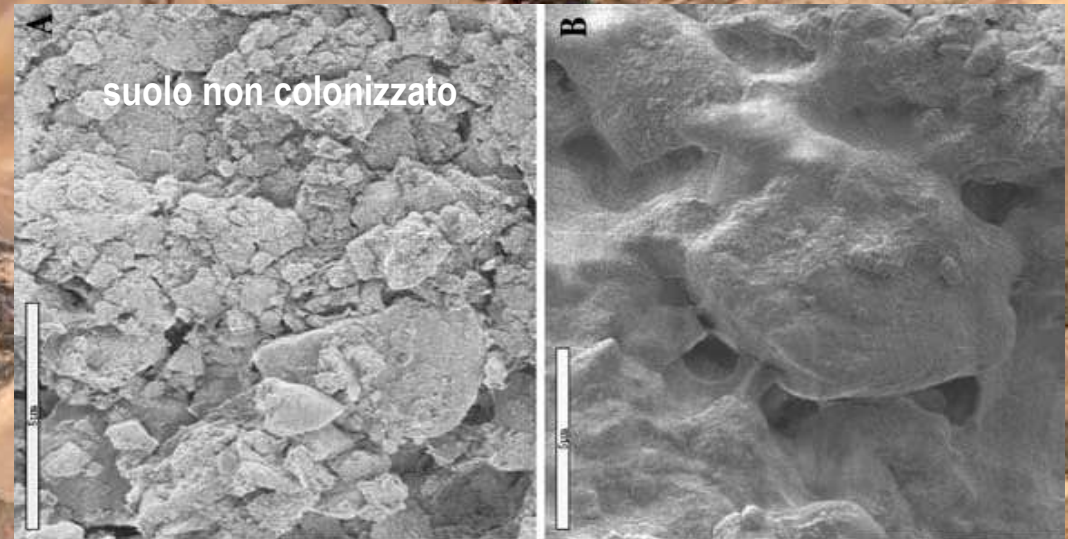
34 anni



17 anni



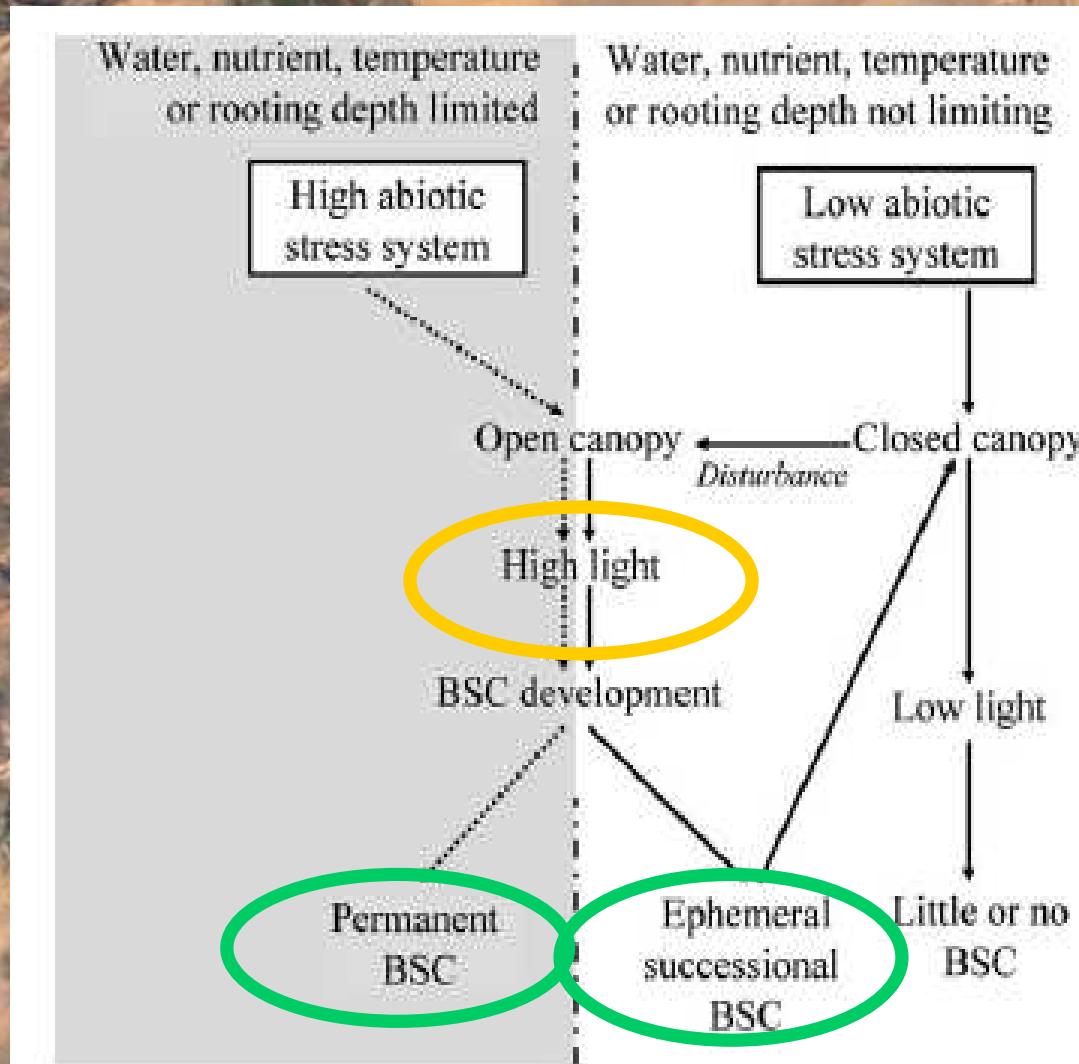
8 anni



cianobatteri filamentosi
tra particelle minerali

1. *Scytonema javanicum*
2. *Nostoc* sp.
3. *Desmococcus olivaceus*
4. *Microcoleus vaginatus*
5. green algae
6. *Euglena*
7. *Phormidium tenue*
8. *L. cryptovaginata*
9. Diatoms

BSC ed effetto delle variabili ambientali



Fattori di stress:

- elevate dosi di radiazione
- escursioni di temperatura
- carenza idrica
- carenza nutrienti
- salinizzazione

Cause:

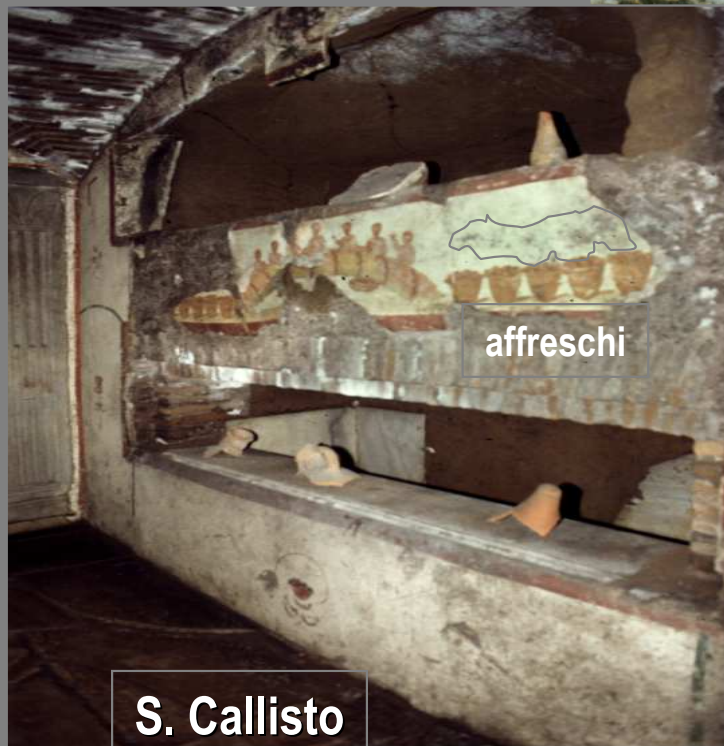
- cambiamenti climatici
- sfruttamento intensivo
- siccità
- incendi
- erosione eolica e idrica

Ambienti ipogei naturali

Grotte dei pipistrelli, Zuheros



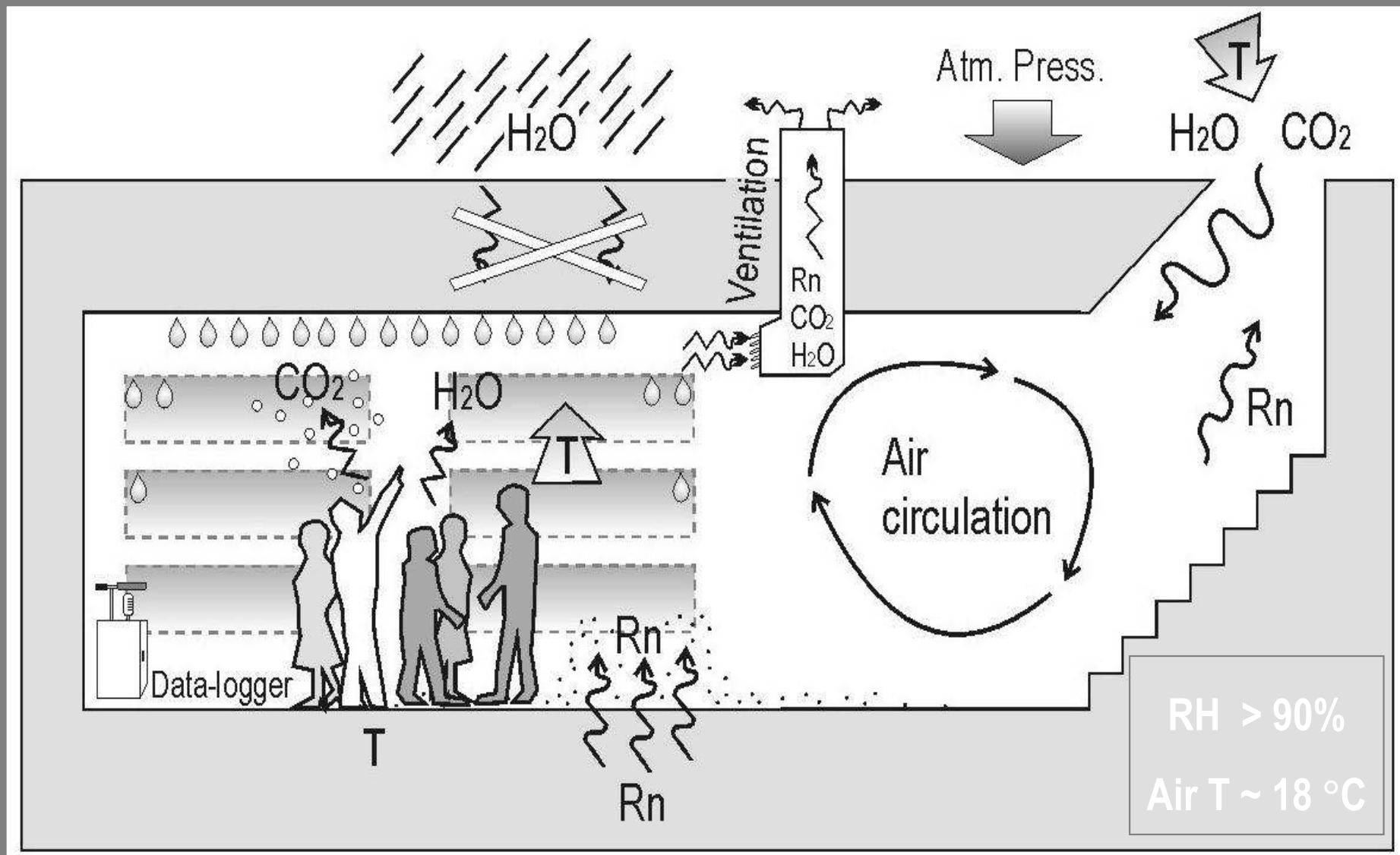
Biofilms nelle Catacombe Cristiane di Roma (I - IV secolo)



Photosynthetic Photon Flux Density

site	RH (%)	T (°C)	$\mu\text{mol m}^{-2}\text{s}^{-1}$	$\text{W} \cdot \text{m}^2$	lux	pH
CSC5	95.0	16.9	1.7	0.75	240	6.29
CSC6b	96.5	16.8	0.9	0.19	50	6.67
CSC7	90.6	17.1	0.8	0.16	70	6.28
CSC9c	94.0	17.2	0.6	0.14	35	8.15*
CSC12b	97.9	16.8	2.5	0.50	140	6.85
CP5	99.9	16.9	0.5	0.14	27	7.59
CP6	99.9	15.6	0.2	0.06	12	7.57
CP7	91.6	16.2	0.4	0.13	28	5.99
CP8a	99.9	16.5	0.6	0.14	31	7.34
CP8b	99.9	16.6	0.2	0.05	9	7.28
CP9	99.9	17.8	0.5	0.13	24	7.58

Catacombe di S. Callisto



Aumento del vapore acqueo e dell'anidride carbonica