

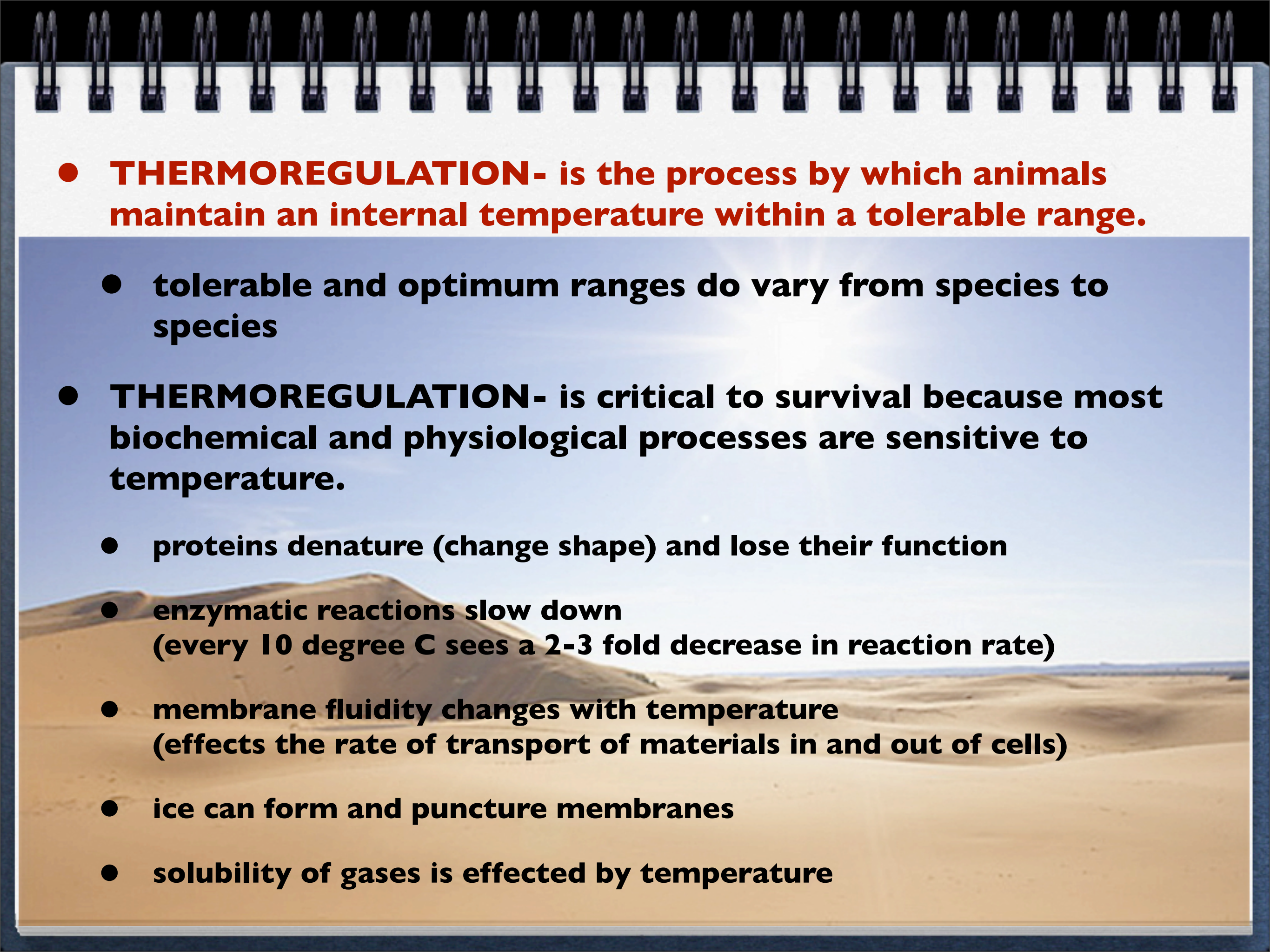
Life's Common Challenges

Thermoregulation

A blue spiral-bound notebook with silver rings at the top. The text is centered on the page.

Life's Common Challenges

Introduction

- 
- **THERMOREGULATION-** is the process by which animals maintain an internal temperature within a tolerable range.
 - tolerable and optimum ranges do vary from species to species
 - **THERMOREGULATION-** is critical to survival because most biochemical and physiological processes are sensitive to temperature.
 - proteins denature (change shape) and lose their function
 - enzymatic reactions slow down
(every 10 degree C sees a 2-3 fold decrease in reaction rate)
 - membrane fluidity changes with temperature
(effects the rate of transport of materials in and out of cells)
 - ice can form and puncture membranes
 - solubility of gases is effected by temperature

A blue spiral-bound notebook with silver rings at the top. The word "Animals" is written in white, and "Thermoregulation" is written in yellow below it.

Animals

Thermoregulation

Endothermy & Ectothermy

“source of heat”

- ***Endothermic*** organisms are warmed (from within) mostly by their metabolism
 - ex. birds, mammals
- ***Ectothermic*** organisms gain (from outside) most of their heat from external sources
 - ex. amphibians, lizards, snakes, fish

Note: These modes are not mutually exclusive!

Remember life's adaptations
are all about “trade offs”

Endotherms...Pros!

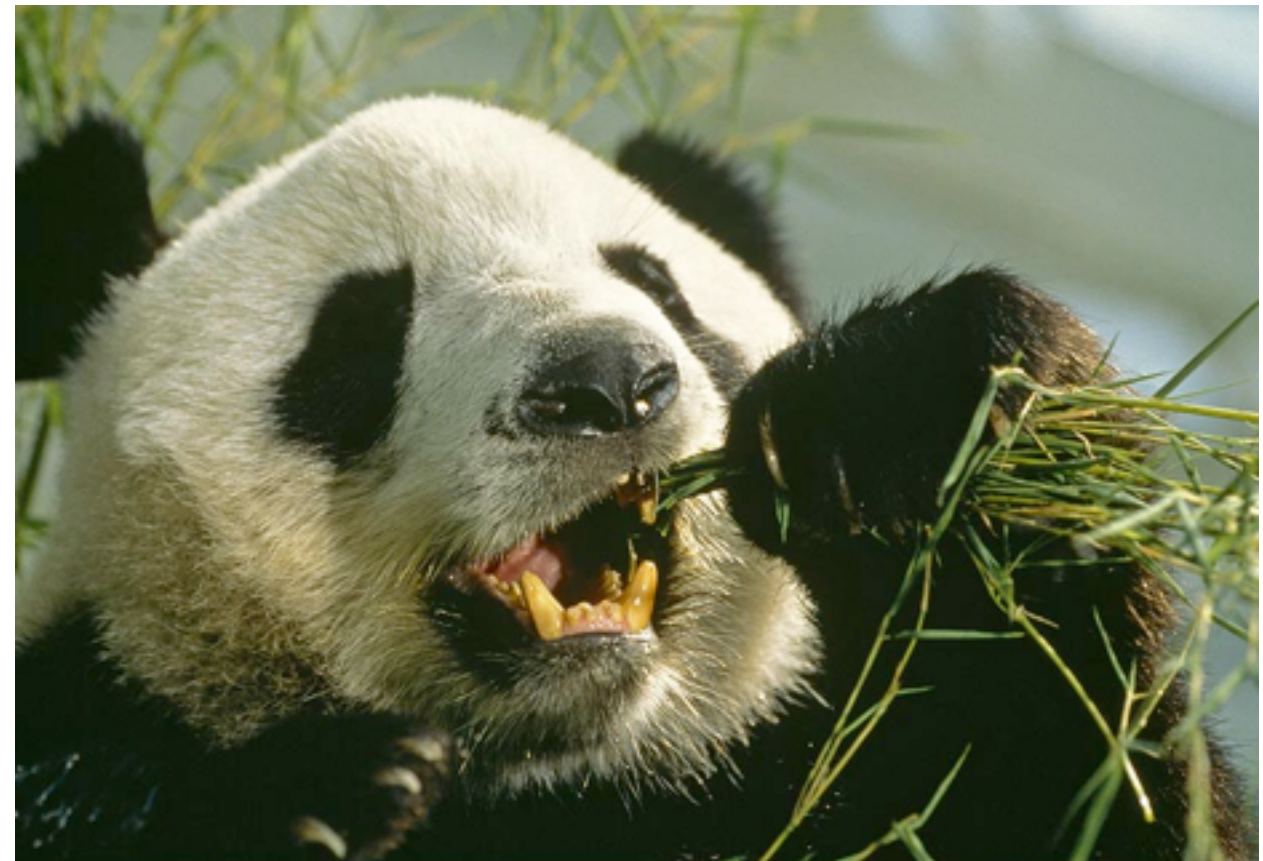
- **Endotherms** can maintain stable body temps even with large fluctuations in environmental temps
- **Endotherms** function well in cold climates (not so for ectotherms)
- **Endotherms** function well in hot climates (they have cooling mechanisms)



Remember life's adaptations
are all about “trade offs”

Endotherms...Cons!

- **Endotherms** do not tolerate large changes in their internal temps, inside temps are tightly regulated.
- **Endotherms** must consume large amounts of food to fuel their metabolisms



Remember life's adaptations
are all about “trade offs”

Ectotherms...Pros!

- **Ectotherms** can tolerate a larger range of internal temps
- **Endotherms** do not require large amounts of food



Remember life's adaptations
are all about “trade offs”

Ectotherms...Cons!

- **Ectotherms** do not tolerate sudden and or large fluctuations in environmental temperatures
- **Ectotherms** are rarely active in cold climates

In spite of this ectothermy is a successful strategy
for thermoregulation supported by the abundance
and diversity of ectothermic organisms

Variation in Body Temperature

- **Poikilotherm** organisms whose body temp varies with the environment
- ex. largemouth bass
- **Homeotherm** organisms whose body temp remains relatively constant
- ex. river otter

Oddly: There is no fixed relationship between the “source of heat” and the “stability of body temperature”

Some marine fish have more stable internal temps than some birds and mammals!

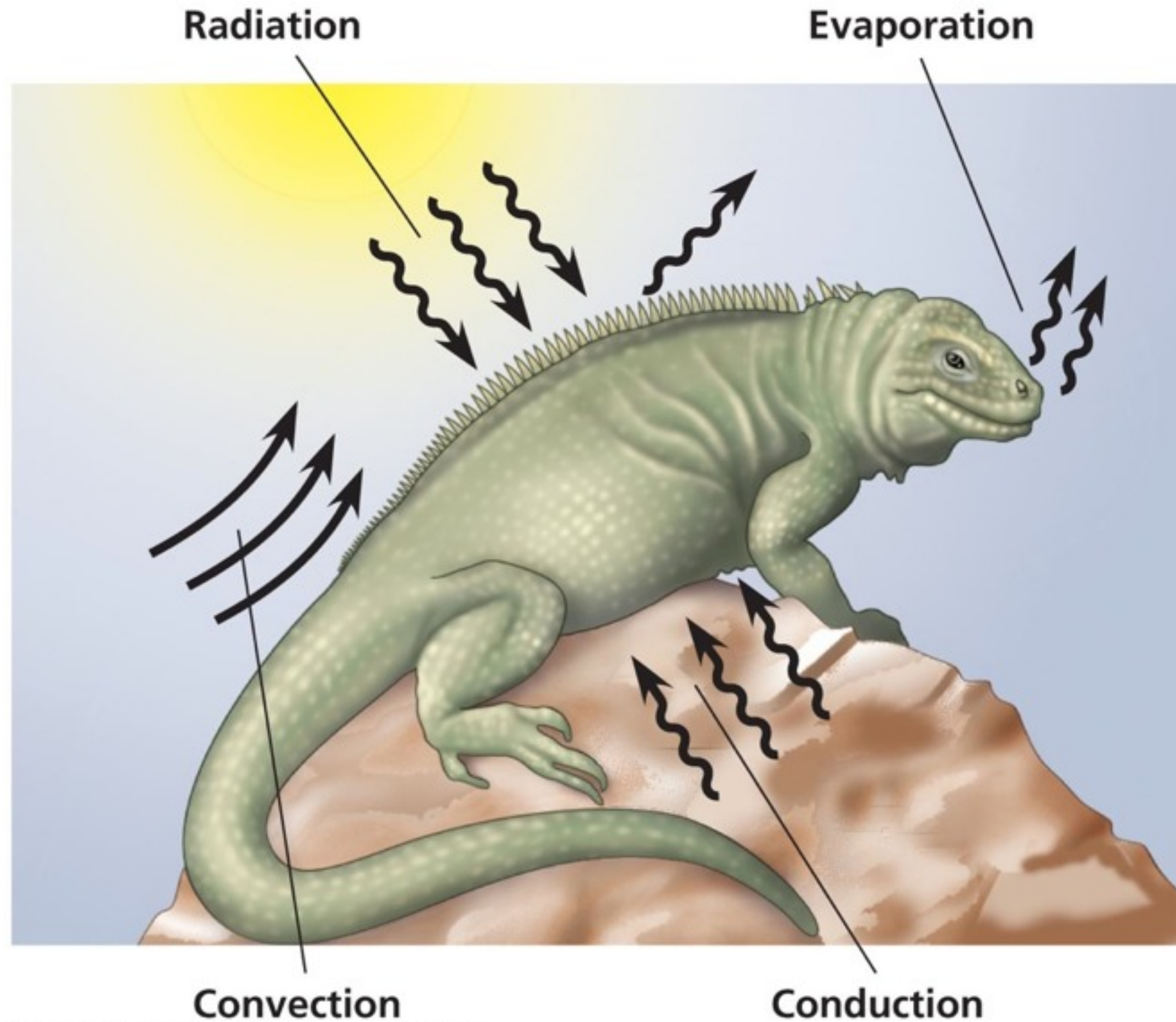
Balancing Heat Loss and Gain

- **Thermoregulation** depends on the organisms ability to control the exchange of heat with its environment
- The essence of **Thermoregulation** is balancing heat loss and heat gain!
- Any organism or object exchanges heat by one or more the following physical processes...
 - Radiation, Evaporation, Convection, Conduction

Note: Heat is always transferred from the object of higher temperature to the object of lower temperature.

Radiation is the emission of electromagnetic waves by all objects warmer than absolute zero

Evaporation is the removal of heat from the surface of a liquid that is losing some of its molecules as a gas.



Conduction is the direct transfer of thermal motion (heat) between molecules of objects in contact with one another.

Convection is the transfer of heat by the movement of air or liquid past a surface.

Insulation

- **Insulation** reduces flow of heat between organisms and their environment
- major adaptation in birds and mammals
 - hair, feathers and adipose tissue (fat)
- Organisms can adjust their insulating layers accordingly
 - raising of fur or feathers, traps air creating a thicker layer
 - “goose bumps” are vestige from our furry ancestors
- oily secretions onto fur or feathers, repels water
- marine mammals have “blubber” (thick layer of fat)
 - important because heat to water transfer is 50-100X more rapid than heat to air transfer

Blubber is so effective that marine mammals can maintain internal body temps of 36-38C or 97-100F



Circulatory Adaptations

- Circulatory systems provide a major route for the flow of heat between the internal and external environments.
- Adaptations that adjust blood flow play a significant role in thermoregulation.
- One such adaptation involves the adjustment of vessel diameter.
 - Vasodilation opens vessels which consequently results in heat loss. Widening the vessels places blood closer to the skin (surface for heat exchange)
 - Vasoconstriction closes vessels which consequently lessens heat loss. Smaller vessels decrease blood flow and as a result heat exchange.

Present in both endotherms and ectotherms

Constricted



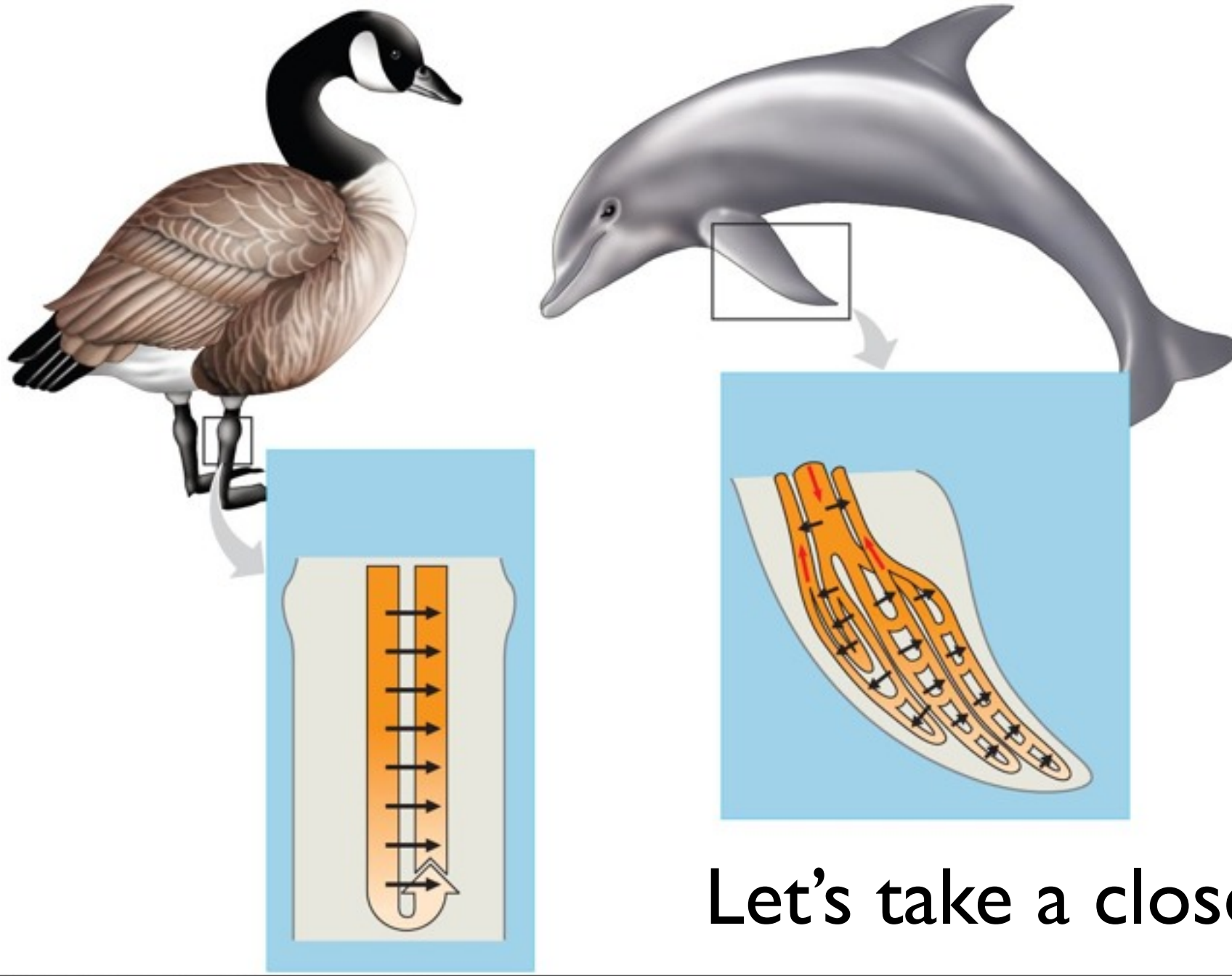
In which Iguana(s)
is the blood
vessels likely
dilated?
constricted? Why?



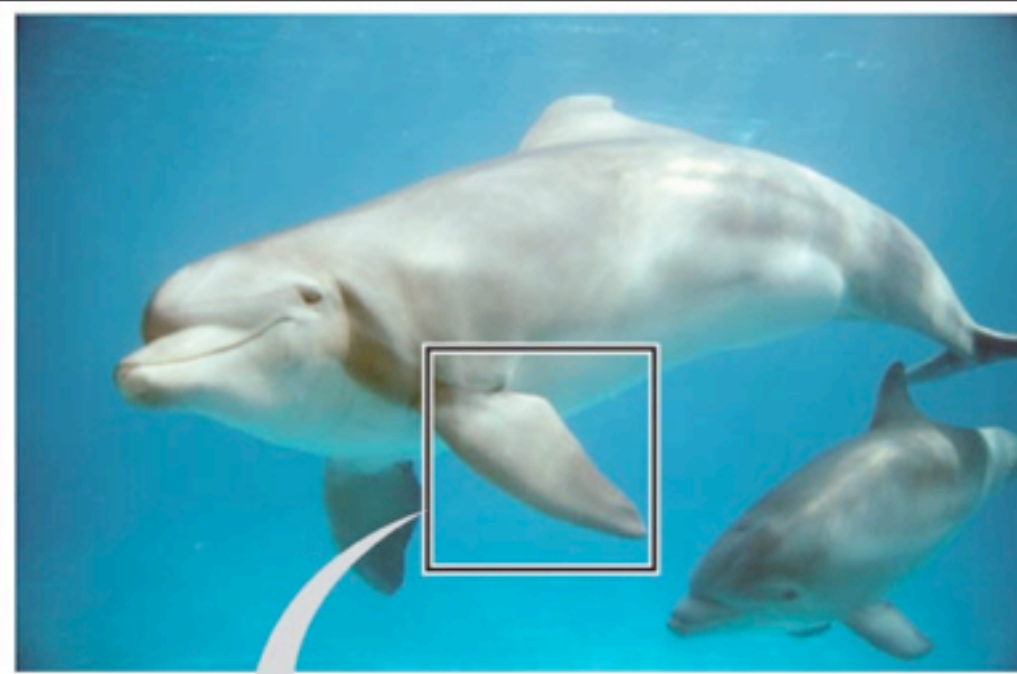
Dilated

Circulatory Adaptations

- Another circulatory adaptation relies on a **Countercurrent Exchange**, the transfer of heat (or solutes) between fluids that are flowing in opposite directions

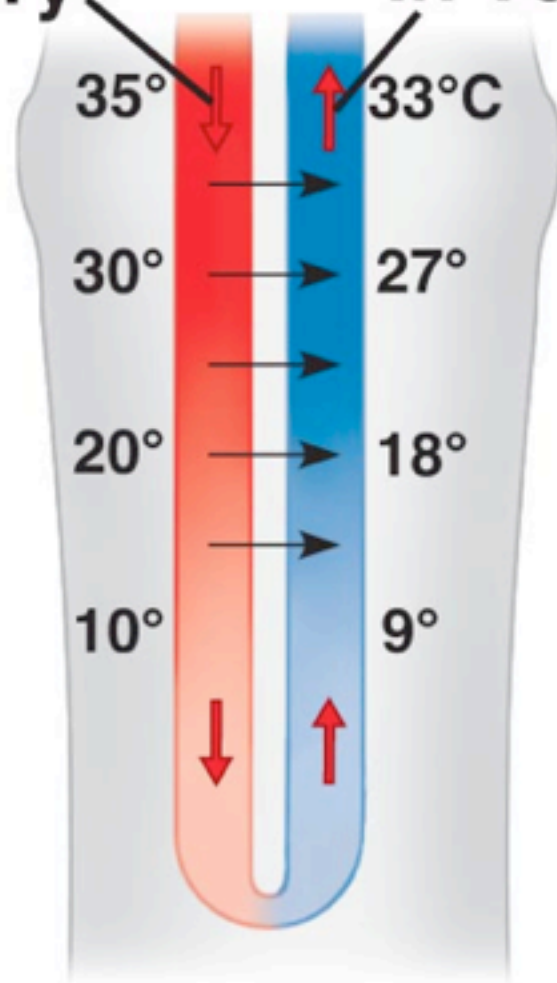


Let's take a closer look...



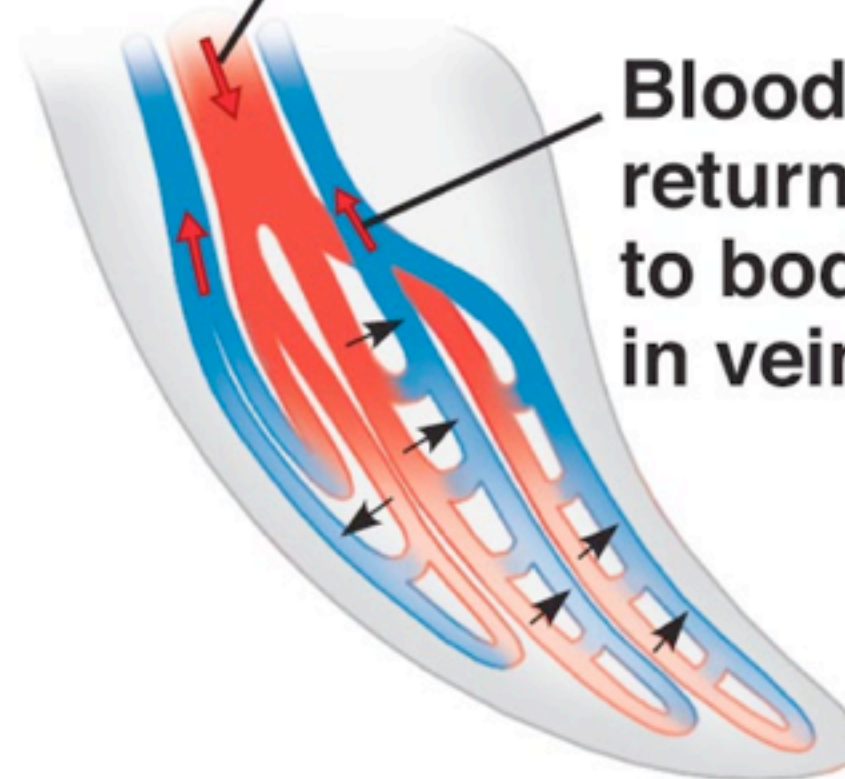
**Blood from
body core
in artery**

**Blood
returning to
body core
in vein**



**Blood from
body core
in artery**

**Blood
returning
to body core
in vein**



Cooling by Evaporative Heat Loss

- Thermoregulation requires cooling as well as warming.
- Evaporation is the only way to keep body temperature from rising.
- Terrestrial animals lose water (evaporation) through skin and respiratory surfaces.
 - remember water absorbs considerable amount of heat and much is carried away during evaporation
 - panting, sweating and bathing

Let's take a closer look...

Behavioral Responses

- Many organisms, both endotherms and ectotherms thermoregulate through behaviors.
- These behaviors may be simple (moving into shade or sun) or complex (migration and hibernation).
- Some behaviors involve postures that minimize or maximize surface area

“obelisk” posture
minimizes sun exposure,
thus reducing heat gain



Behavioral Responses

- Honeybees cluster in cold weather and then bees rotate from warm center to cold edges and back and forth.
- This social behavior requires tremendous amounts of energy, the main function of honey stored in the hive is energy for staying warm during cold weather.
- Honeybees carry water to the hives center and then fanning with their wings they promote evaporation and convection.
- A colony of honeybees uses many of the same thermoregulatory mechanisms seen in individuals

Adjusting Metabolic Heat Production

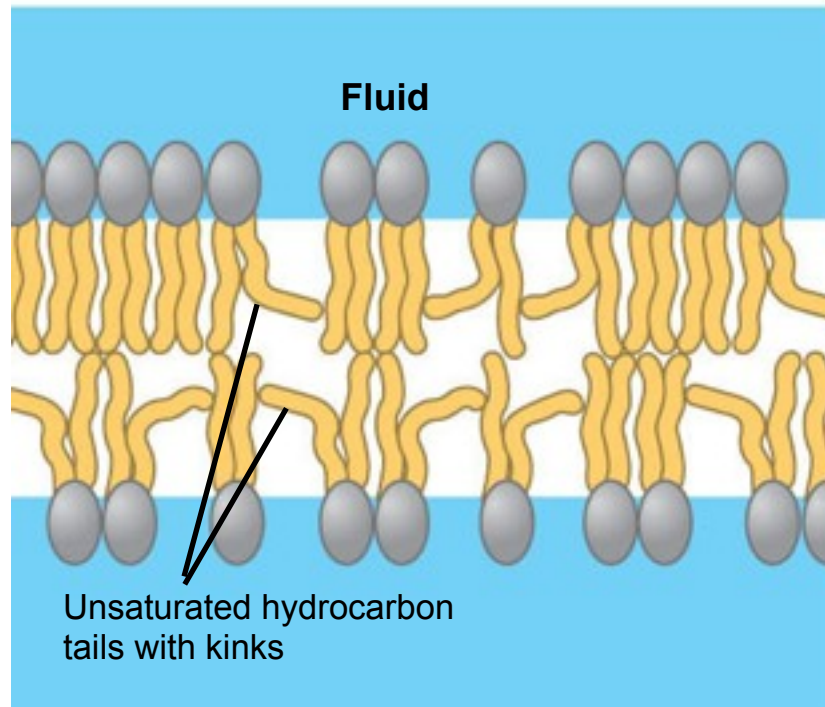
- Endotherms can vary heat production-***thermogenesis***-to match changing rates of heat loss.
- ex. increase muscle activity through moving or shivering.
- Check this out...chickadees can maintain a body temp of 40°C (104 °F) in temps as low as -40 °C (-40 °F)
- Some mammals can generate heat at the cellular level through increase ATP production- *nonshivering thermogenesis*.
- *Brown fat* located in the neck and shoulder region is specialized for rapid heat production
- brown fat accounts for 5% of total body weight in human infants

Acclimatization in Thermoregulation

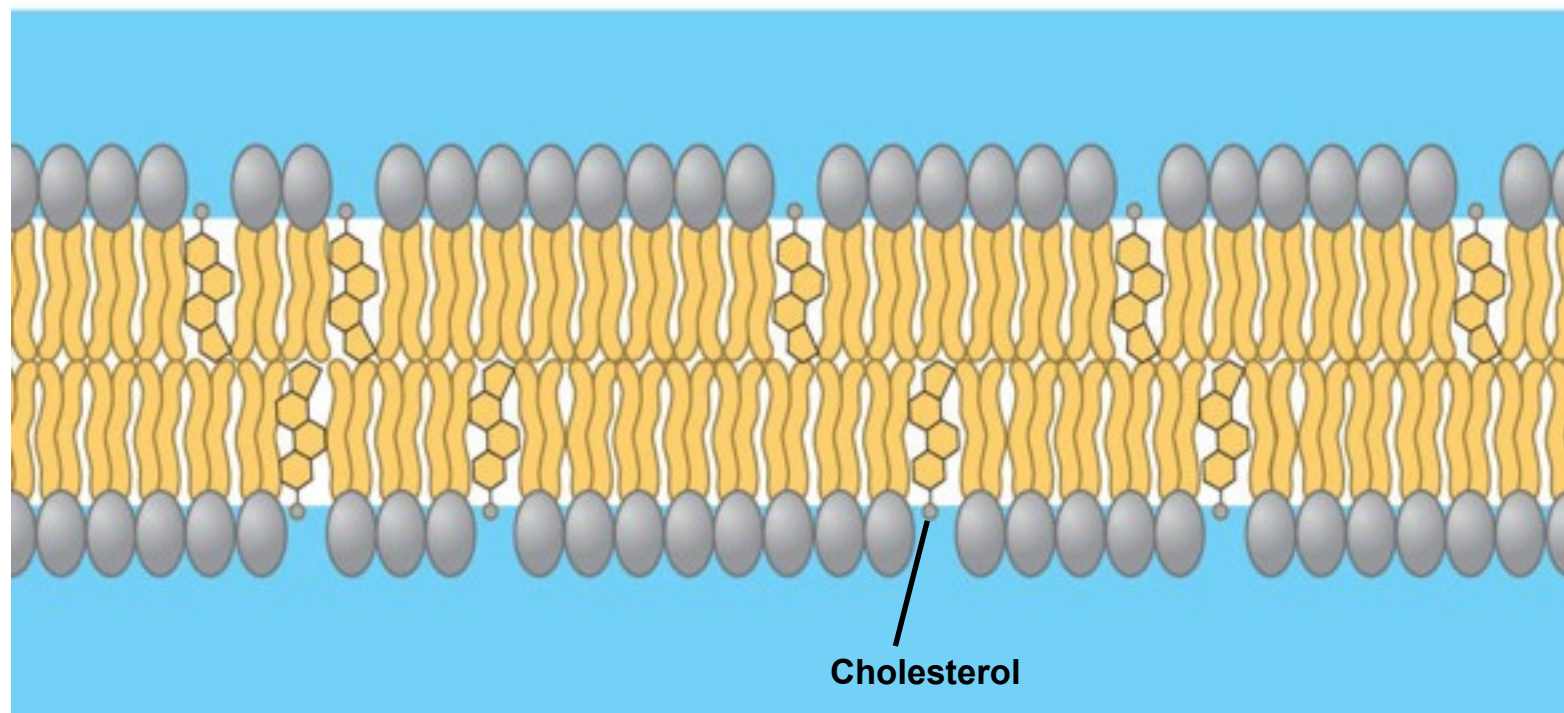
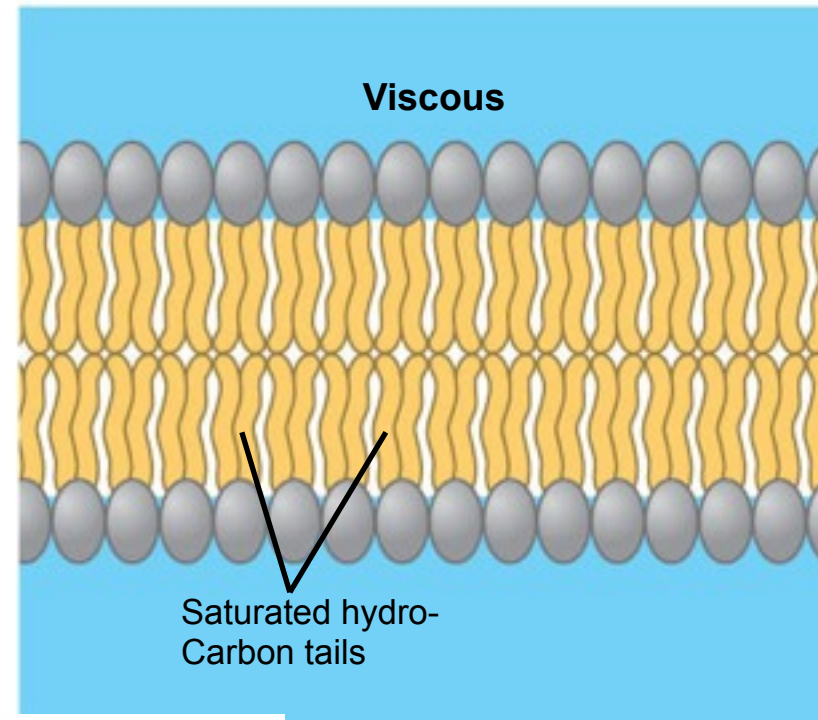
- Organismal Level: Some animals adjust their insulating layers seasonally.
 - ex. growing a thicker coat during the winter months and shedding the excess during the summer months.
- Cellular Level: Some cells produce variants of enzymes that have the same function but operate at different optimal temps.
- Cellular Level: Some cells alter their proportions of saturated and unsaturated lipids that make up their membrane.
 - ex. winter wheat
- Cellular Level: Some cells can produce “antifreeze compounds” that prevent ice formation in their cells.
 - ex. certain fish can survive in water as cold as -2°C (28°F)

How would the proportions of lipids in the membrane of winter wheat change during winter? During summer?

Winter



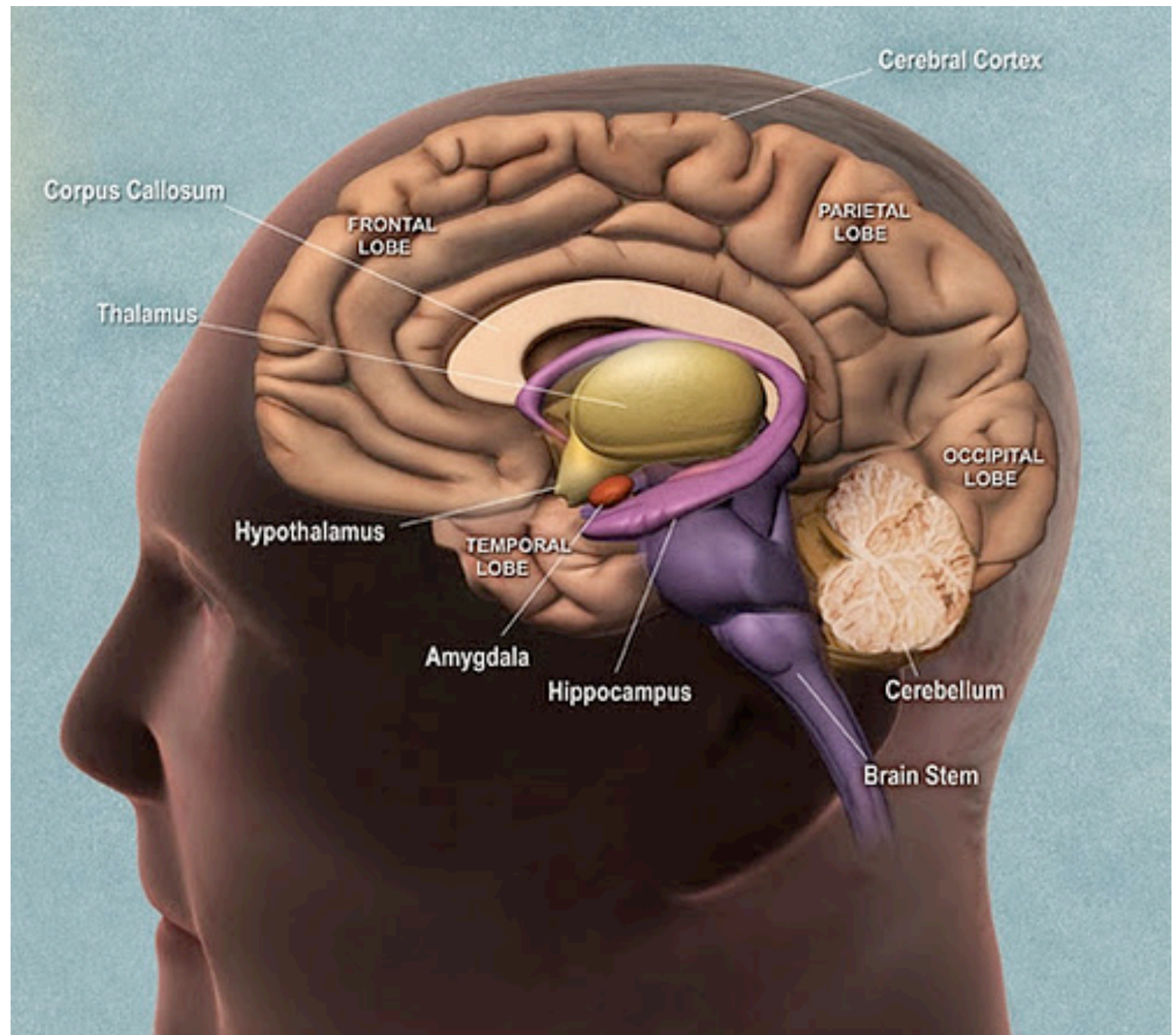
Summer



Adding cholesterol can make a viscous membrane more fluid OR it can make a fluid membrane more viscous

Physiological Thermostats & Fever

- A complex feedback system is responsible for regulating body temps in mammals.
- A region in the brain called the *hypothalamus* serves as the body's thermostat.



Sweat glands secrete sweat, which evaporates, cooling the body.

Thermostat in hypothalamus activates cooling mechanisms.



Blood vessels in skin dilate: capillaries fill; heat radiates from skin.

Body temperature decreases; thermostat shuts off cooling mechanisms.

Increased body temperature

Homeostasis: Internal temperature of 36–38°C

Body temperature increases; thermostat shuts off warming mechanisms.

Decreased body temperature

Blood vessels in skin constrict, reducing heat loss.



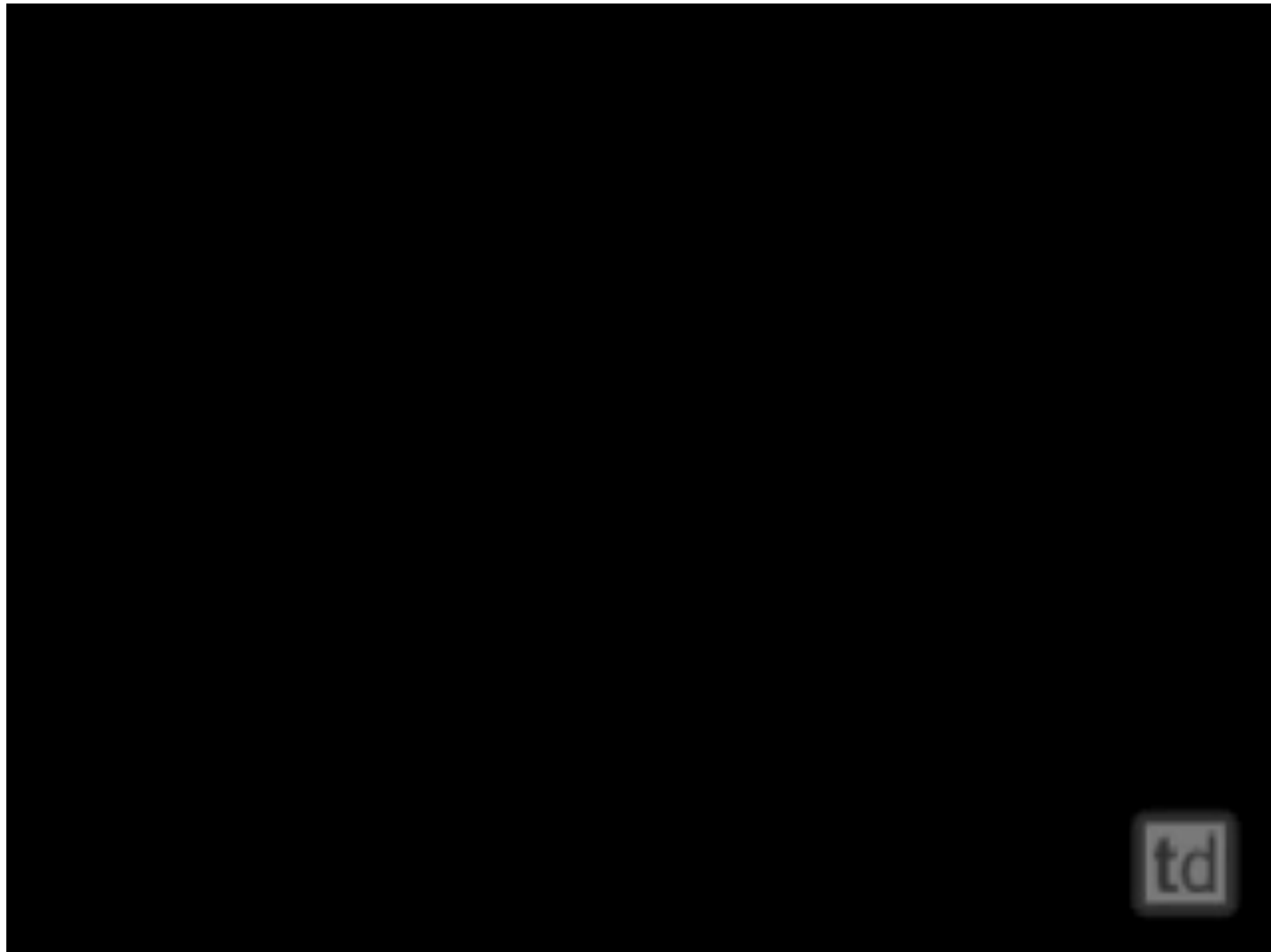
Thermostat in hypothalamus activates warming mechanisms.



Skeletal muscles contract; shivering generates heat.

Physiological Thermostats & Fever

- Certain bacterial and viral infections bring about an increase in the body's temperature set point...fever.
- Fever makes it difficult for pathogens to reproduce.



Can ectotherms develop a fever?

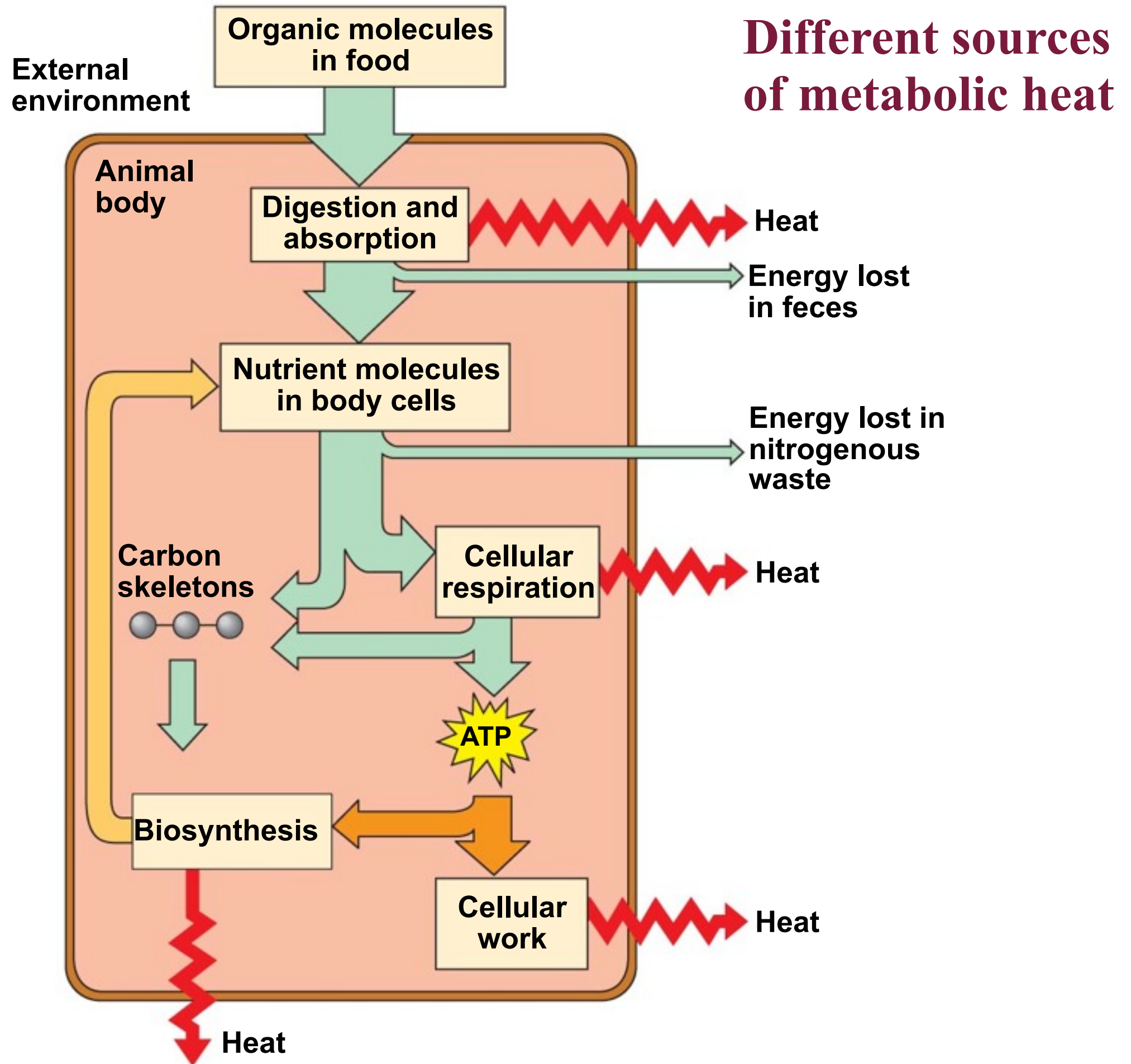
- No... and Yes
 - Only endotherms develop fevers however ectotherms like lizards can elevate their body temps through behavior (like sunbathing) and thus fight infection in the same way.

Most of the time, fever isn't dangerous in itself, but a patient will feel more comfortable at a lower temperature. In a dramatic demonstration of fever's benefits, researcher [Matthew Kluger](#) infected desert iguanas with bacteria.

Because these lizards are cold-blooded, they could only warm their bodies by seeking outside heat -- in this case, sunlamps. All except one of 13 iguanas sought the warmth to raise their temperatures, and those 12 survived; the other one died.

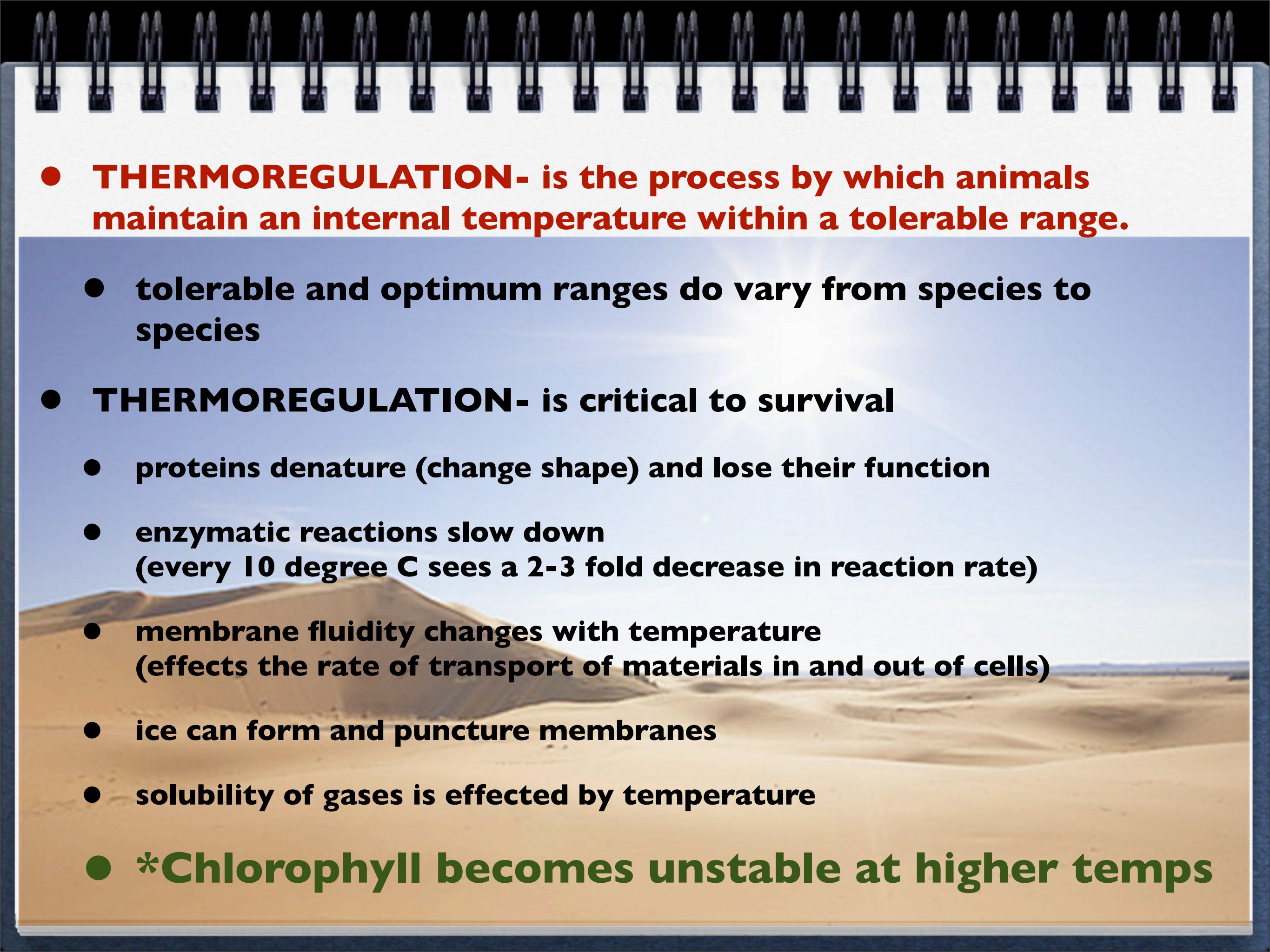
After that, Kluger injected 12 other iguanas with live bacteria, and also gave them a fever-fighting drug. Five of them failed to develop a fever, and died as a result. The other seven, which somehow became feverish despite the drug, survived.

Despite experiments like this, scientists haven't yet answered all their questions about this common and ancient body symptom.



Plants

Thermoregulation

- 
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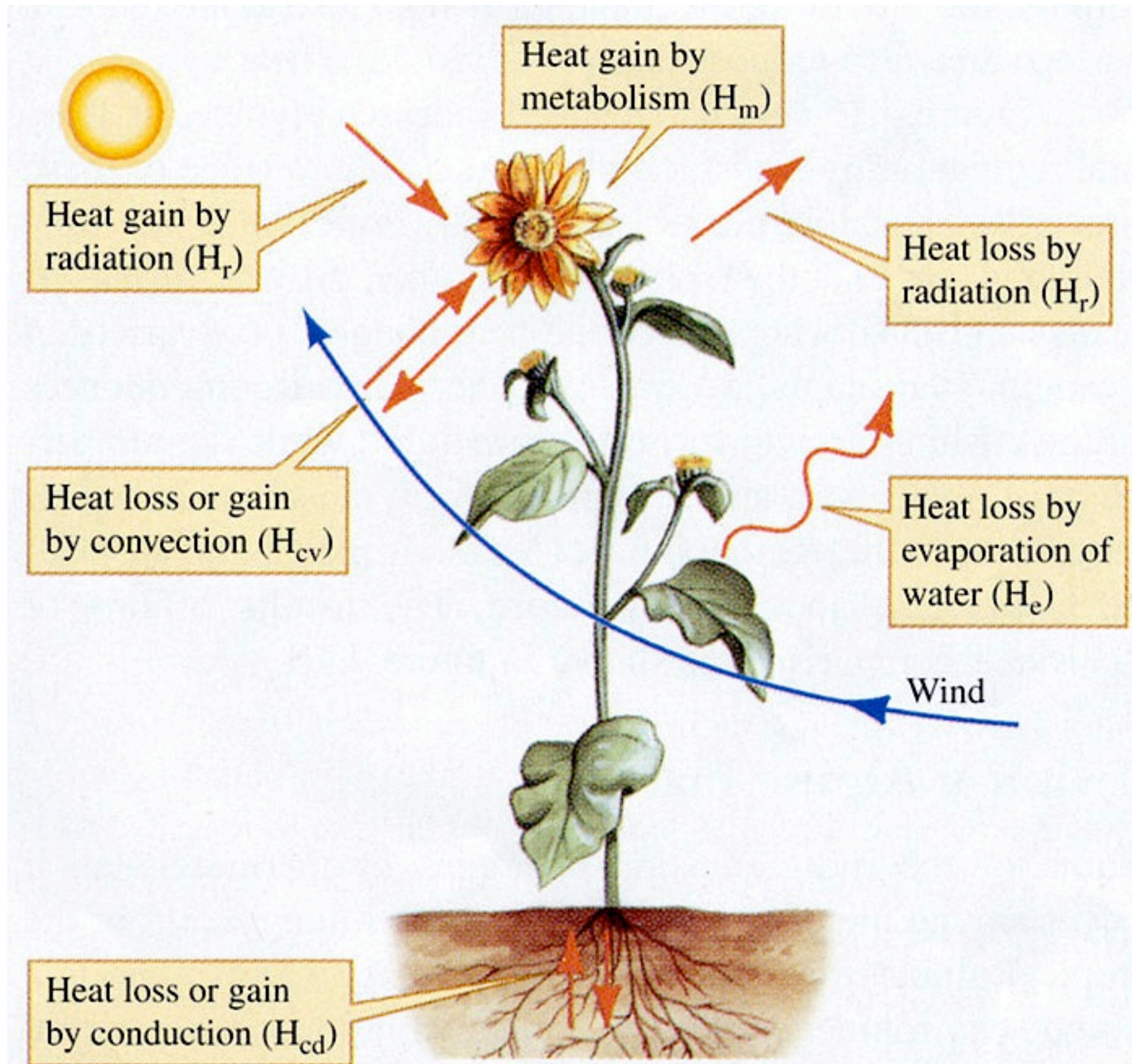
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 - ice can form and puncture membranes
 - solubility of gases is effected by temperature
 - ***Chlorophyll becomes unstable at higher temps**

Balancing Heat Loss and Gain

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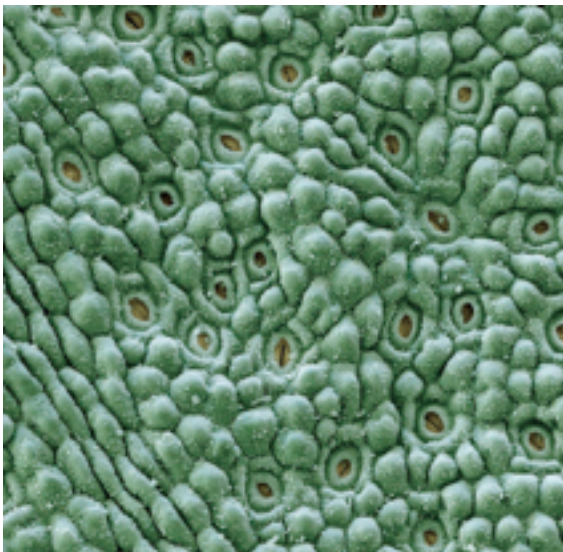
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Balancing Heat Loss and Gain



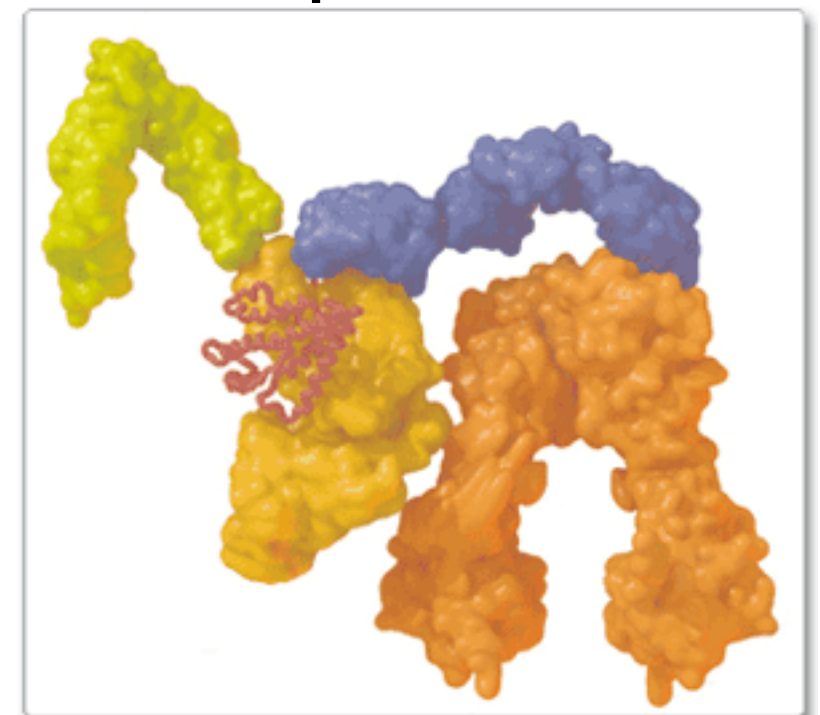
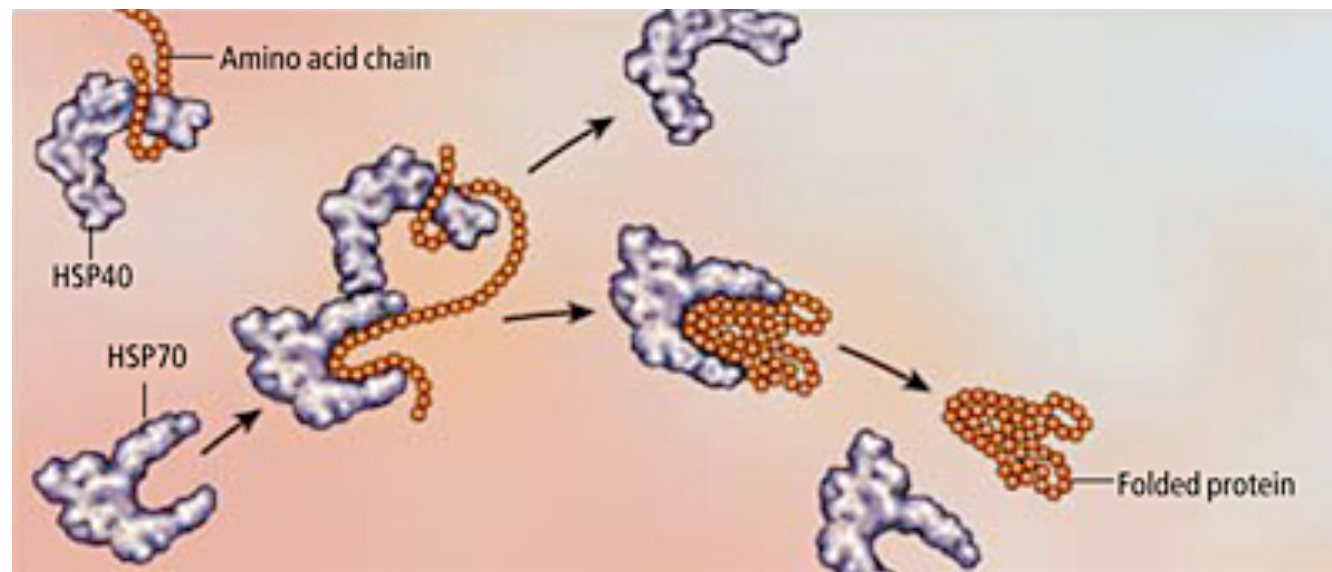
Heat Stress

- Excessive heat can harm or kill a plant by denaturing proteins and disrupting metabolism
- Transpiration (“plant sweating”) is an adaptation that can keep a leaf 3-10 °C below the ambient air temperature
- however transpiration has its limits, too much water loss can dehydrate a plant and slow its rate of photosynthesis
- on hot dry days plants are forced to close their stomates to conserve water, this of course reduces evaporative heat loss through transpiration



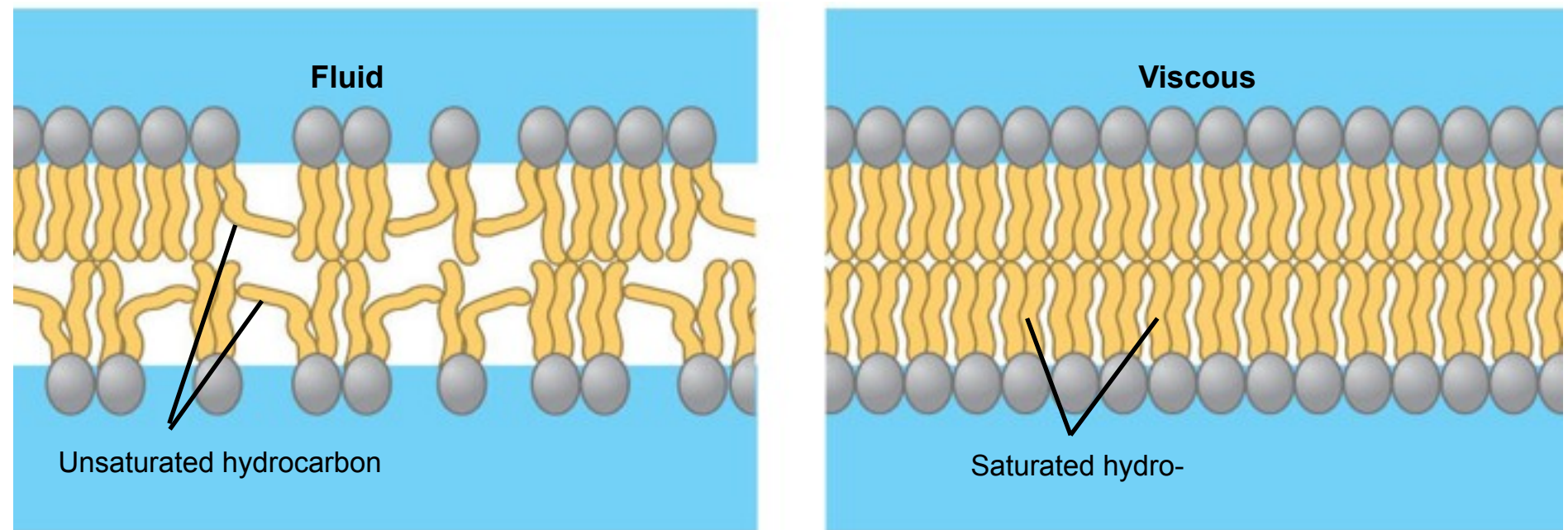
Heat Stress (*continued*)

- When transpiration can no longer cool the plant leaves a backup mechanism is relied upon...
- Plant cells respond by producing “**heat shock proteins**”.
- These proteins help prevent other proteins from denaturing
 - Some may help denatured proteins fold back into their functional shapes
 - Others may bind to important proteins to keep them from denaturing in the first place



Cold Stress

- Cold temperatures (not freezing) most effect a plants plasma membrane.
- Cold temperatures make membranes more viscous and alters the membranes ability to transport materials into or out from cell
- Plants respond by altering their membrane composition
- Recall...



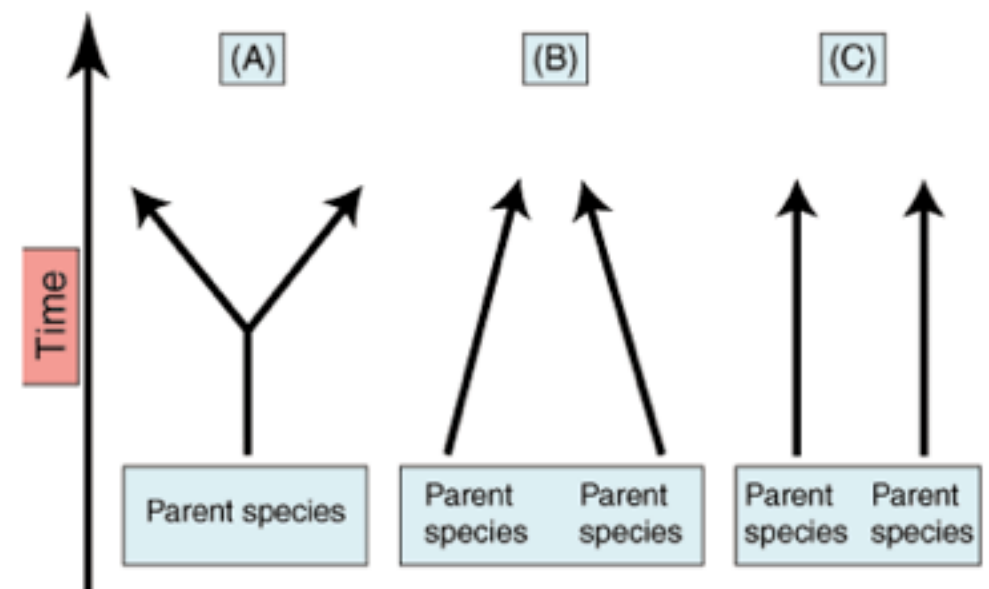
Such modifications takes hours to days which explains why unseasonably cold weather or fast moving cold fronts are so stressful and potentially dangerous

Cold Stress (Freezing)

- Background Information: Adding solutes to water lowers water's freezing point.
- Water's freezing point is 0 °C
- In subfreezing temps the plant cell's cytosol rarely freezes because it contains many solutes
- The water found in between plant cells and in plant cell's walls however contain far less solutes and will therefore readily freeze.
- The Problem: When this water freezes the water potential outside the cell is lowered and water leaves the cytosol, which causes the solute concentration inside the cell to become harmful and potentially deadly to the cell

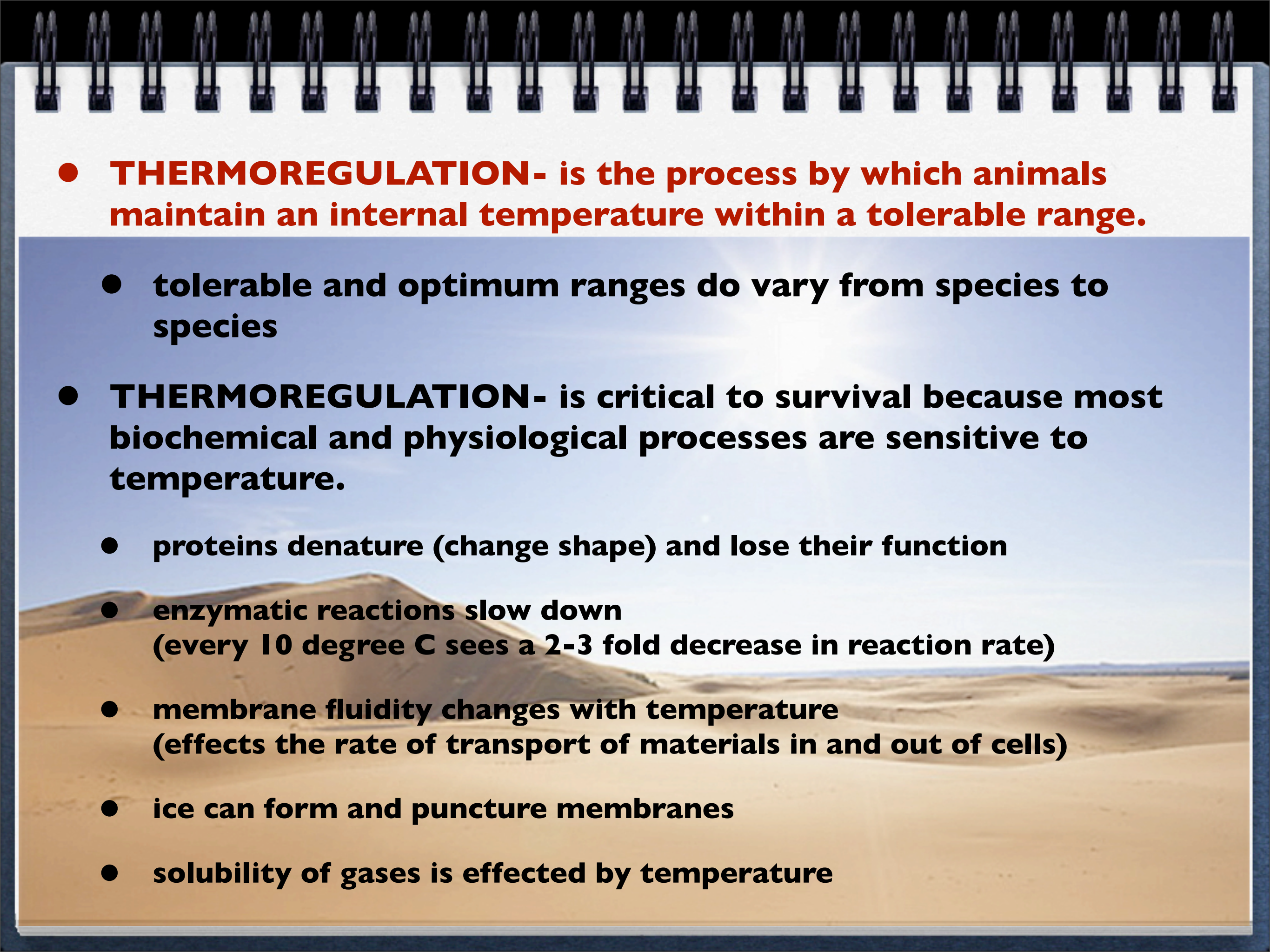
Cold Stress (Freezing)

- Solutions: A well hydrated plant is a good start.
- Some plants will produce produce solutes internally that are well tolerated at high concentrations in the event that water loss occurs
- Plants will also adjust the lipid composition of their plasma membrane to maintain proper fluidity.
- Plants also contain “antifreeze proteins” first discovered in arctic fish, that prevent ice crystals from forming.
- These proteins have slightly different conformations but their amino acid sequences are very different from animals’ sequences. This suggests *convergent evolution*.



Fungi

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Temperature Stress

- Fungi are eukaryotes and extreme heat and cold pose the same threat to fungi as it did for plants and animals.
- As it turns out there are no unique adaptations for dealing with extreme temps, like plants and animals the adaptations for fungi focus on...
 - Preventing proteins from denaturing or helping them refold in the case that they happen to denature
 - Producing temp “hardy” enzymes whose optimal temperatures are abnormally hot or cold
 - Producing “antifreeze” like compounds that prevent water from freezing
 - Adjusting membrane composition to ensure an adequate rate of material transfer across the membrane

Thermophilic Fungi

- There is little research on temp relationships in fungi.
- Much of the research that does exist is from the food industry where heat is commonly used to prevent fungal growth.
- Fungi can be divided into groups by temp requirements for optimal growth
 - Psychrophiles: optima less than 10 °C
 - Mesophiles: optima at room temp 18-22 °C (most fungi)
 - Thermophiles: optima more than 37 °C
(up to 62 °C, they are the only eukaryotes that can live above 45 °C)
 - Note: This data does not address fungal spores and their temp tolerance or requirements that is a separate issue.

Convert these temps above to Fahrenheit.

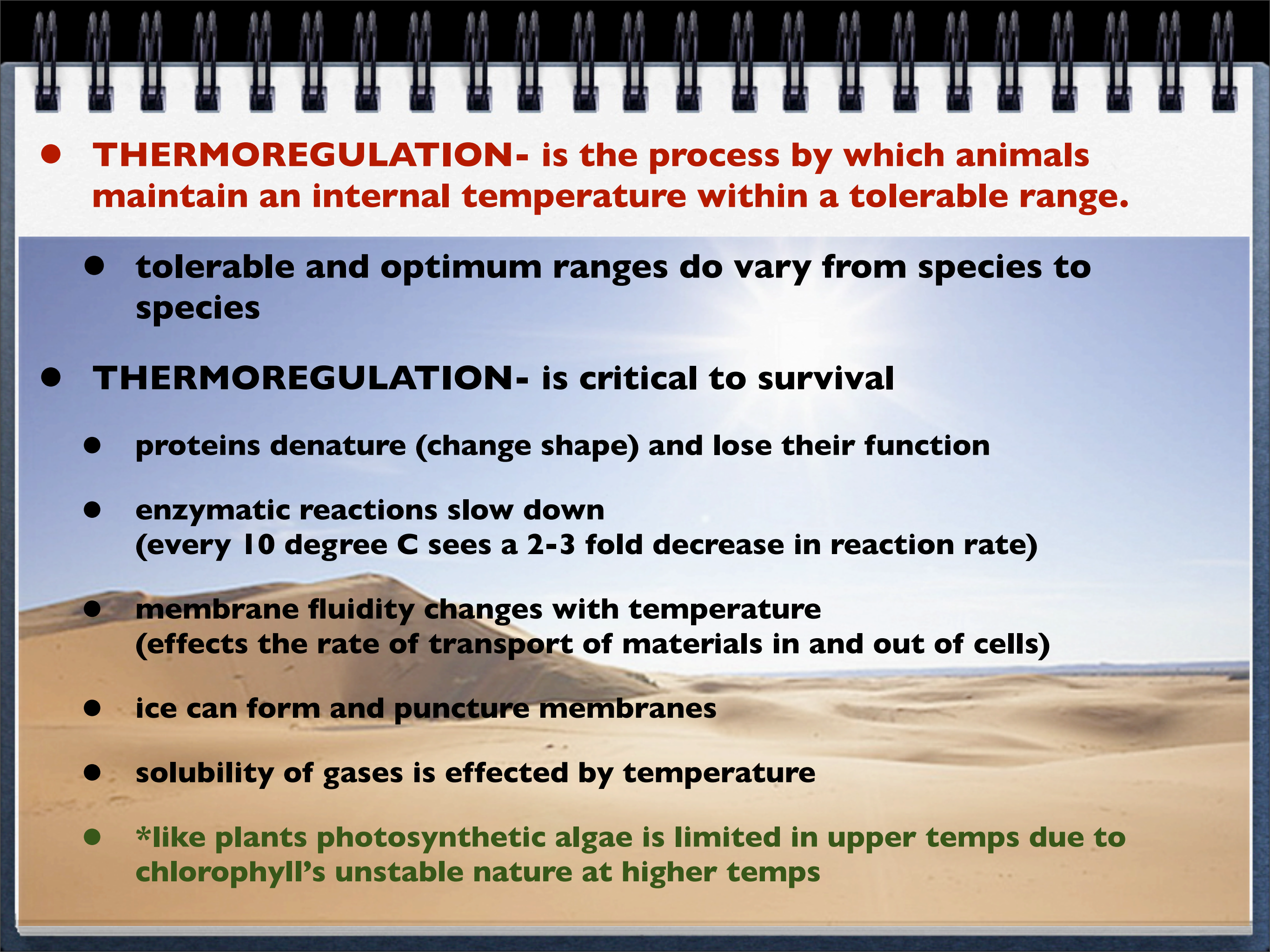
Need a hint... $(9/5)(x \text{ °C}) + 32$

Thermophilic Fungi

- Thermophilic fungi are of interest for scientific and commercial reasons.
- due to their heat tolerant enzymes, for instance some laundry detergents already use these enzymes
- enzymes have long been used in the food and dairy industry
- they are the chief component in compost piles
- they are only approx. 30 species out of 50,000 that can withstand extremely high temps
- Unfortunately the information on thermophilic adaptations is limited because most work continues on the practical applications side of things.

Protists

Thermoregulation

- 
- The background of the slide is a spiral-bound notebook. The top edge shows the metal spiral binding. The page is white, but the bottom half of the slide features a blue-tinted photograph of a desert landscape with rolling sand dunes under a clear sky. The text is overlaid on this image.
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 - *like plants photosynthetic algae is limited in upper temps due to chlorophyll's unstable nature at higher temps

Temperature Stress

- Protists are eukaryotes and extreme heat and cold pose the same threat to protists as it did for plants, animals and fungi.
- As it turns out there are no unique adaptations for dealing with extreme temps, like plants, animals and fungi the adaptations for protists focus on...
 - Preventing proteins from denaturing or helping them refold in the case that they happen to denature
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Temperature Stress

- Some photosynthetic protists have adapted to cold environments.
- ex. Watermelon snow

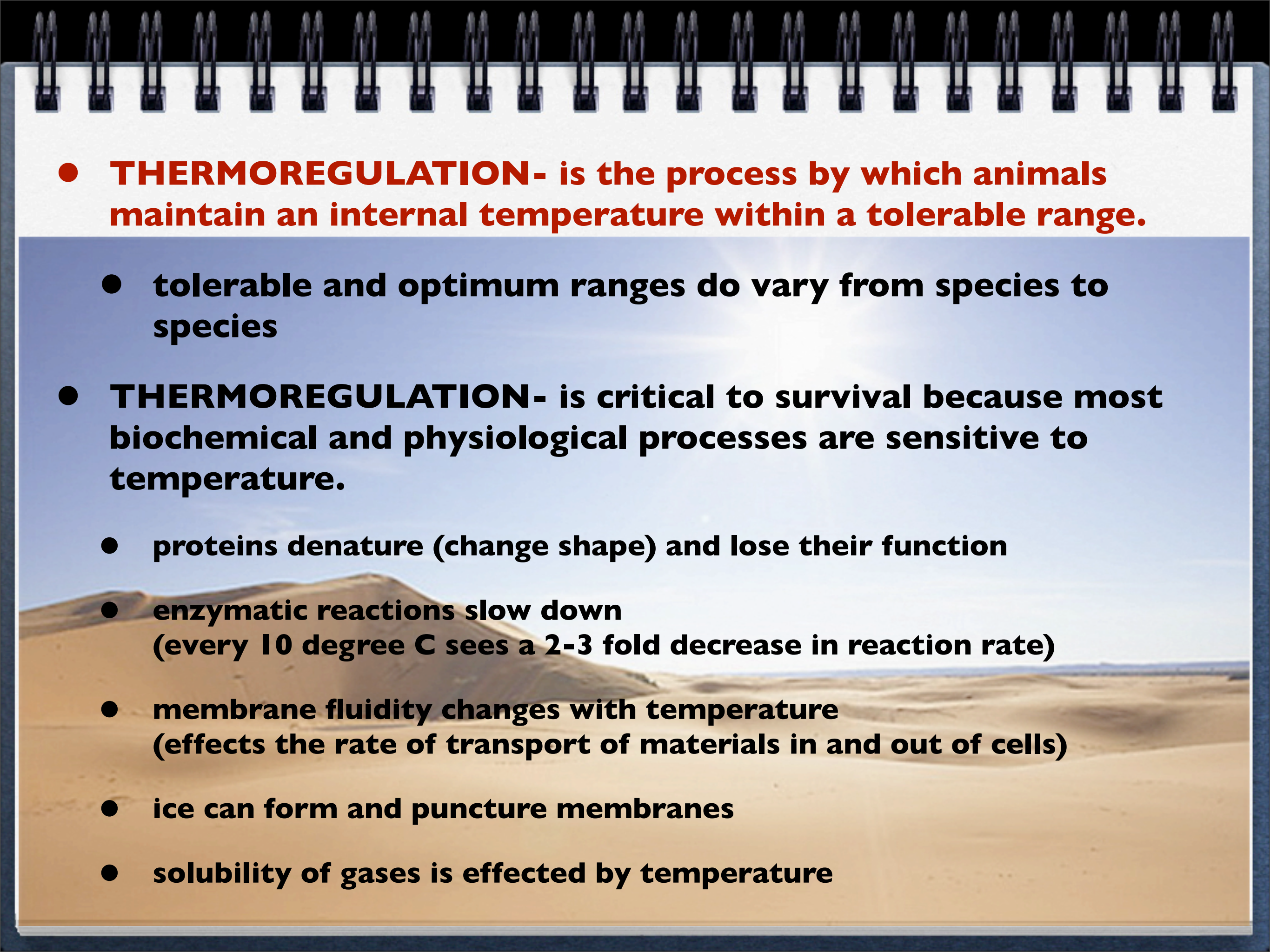


watermelon snow? red snow?

- Pink snow with a slight scent of watermelon!
- Green algae (*Chlamydomonas nivalis*), takes a red color due to secondary red carotenoid pigments that mask the green chlorophyll
 - the red pigments better protect against harmful UV radiation
 - the red pigment also absorbs more heat which melts surrounding snow and provides water for photosynthesis
- This algae thrives in freezing water
- However in winter snow covers the algae and the algae becomes dormant until spring.

Bacteria

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Temperature Stress

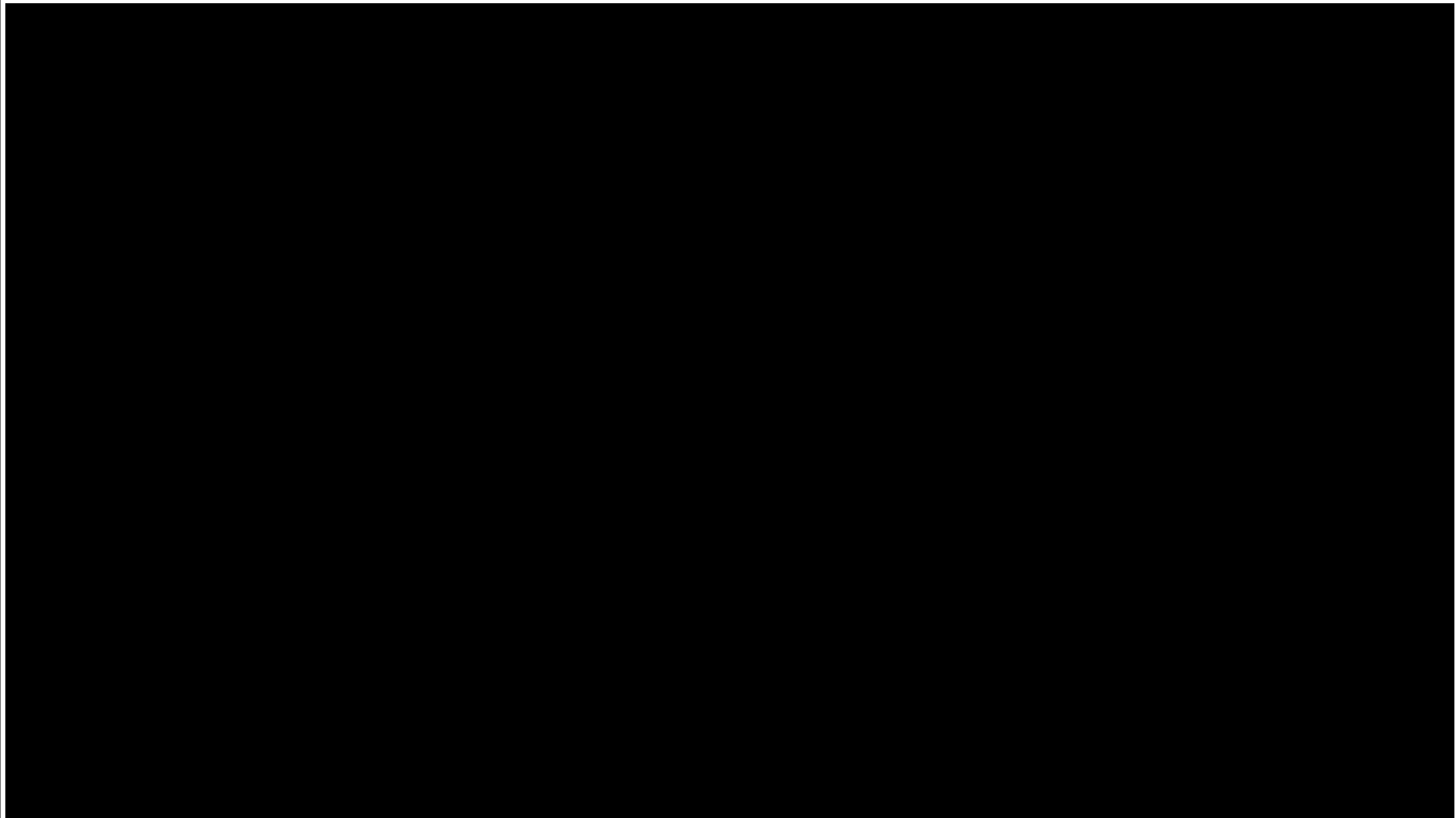
- Bacteria are prokaryotes and extreme heat and cold pose the same threat to bacteria as it did for all other cells and organisms.
- The adaptations for dealing with extreme temps are similar to those seen in other forms of life, the adaptations for bacteria focus on...
 - Preventing proteins from denaturing or helping them refold in the case that they happen to denature
 - Producing temp “hardy” enzymes whose optimal temperatures are abnormally hot or cold
 - Producing “antifreeze” like compounds that prevent water from freezing
 - Adjusting membrane composition to ensure an adequate rate of material transfer across the membrane
 - **Some bacteria have an adaptation where their DNA exists in a “relaxed” state that prevents it from unraveling**

Extreme Thermophilic Bacteria

- Thermophilic bacteria have adapted to the most extreme temperatures!
- Bacteria have been found living in temps as high as 121 °C and as low -20 °C
- Bacteria can be divided into groups by temp requirements for optimal growth
 - Psychrophiles: optima less than 20 °C (range 0-20)
 - Mesophiles: optima ~40 °C (range 10-50)
 - Thermophiles: optima ~ 65 °C (range 45-80)
 - Hyperthermophiles: optima ~100 °C (range 80-120)

What happens to water at 0 °C and 100 °C ?

Extreme Thermophilic Bacteria



Where Are High-Temperature Environments?

Hot Springs

- Yellowstone National Park
- Japan
- Russia
- Iceland
- New Zealand

Deep-Sea Hydrothermal vents

- Found at mid-ocean ridges (Mid-Atlantic Ridge, East Pacific Rise)

Deep Ocean Hydrothermal Vents



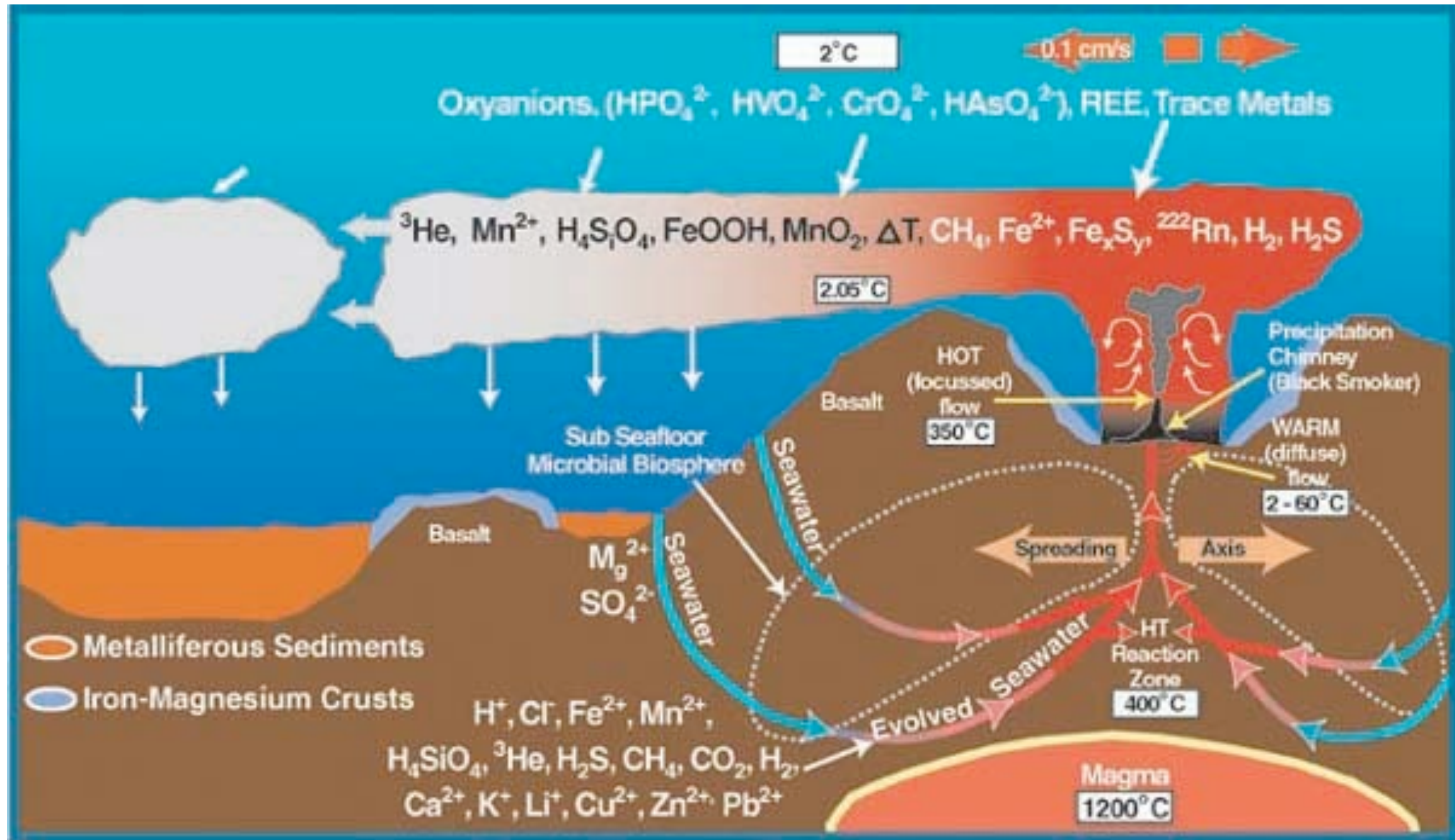
A brief history

- **1960s**: geologists' theory of plate tectonics predicts the existence of submarine "hot spots"
- **1976**: scientists in the Galapagos Rift report anomalous seawater temperatures (among other data) indicating hydrothermal activity
- **1977**: hydrothermal vents are directly observed by scientists in Alvin
- **2005**: Australian mining company Neptune Resources granted the right to explore hydrothermal vent sulfide deposits...

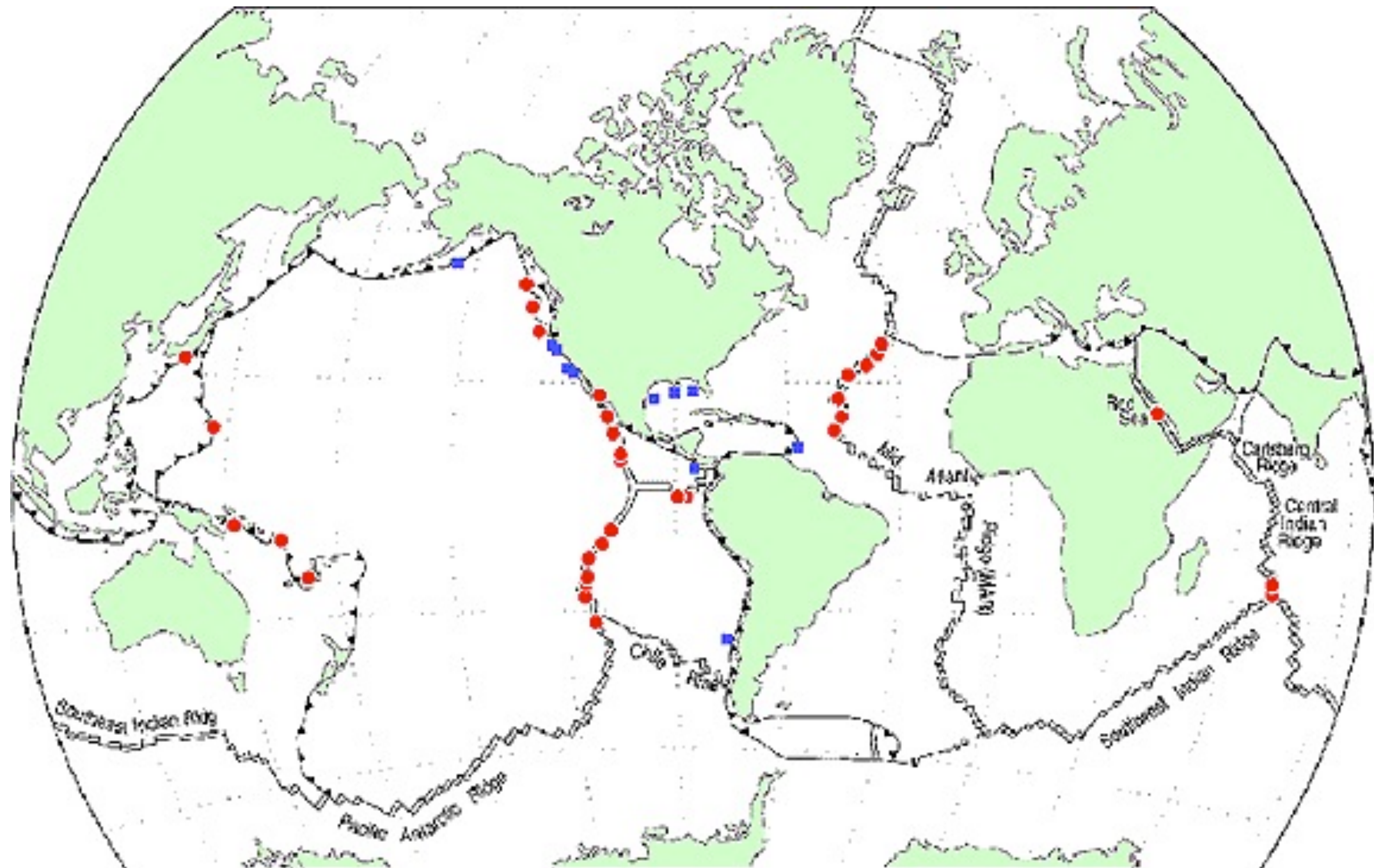
How deep-sea vents form

- At sea-floor spreading centers (e.g. mid-ocean ridges), 1200°C magma pours out of cracks in the lithosphere
- Surrounding water is heated to 300-400°C
- Minerals in sediment precipitate when hot fluid meets cold sea water (2°C)
- Accumulation of minerals builds chimneys, which serve as substrates for microorganisms that can metabolize sulfur and sulfide compounds
- Extreme pressure (>250 atm) keeps water from boiling

Sea-floor spreading



Where vents are found



Hot Springs & Geothermal Features





Yellowstone National Park is home to the world's largest



- ❖ 9000 Hot Springs
- ❖ 500 Geysers
- ❖ 400 Fumaroles
- ❖ 100 Mudpots

Steamboat Geyser – The World's Largest!

Historical Background



1871 Photograph of Thomas Moran taken by William Henry Jackson on the Terraces at Mammoth Hot Springs.

Rumors of a spectacular “Wonderland” began to circulate among fur trappers in the mid 19th century. The first official U.S. government survey party was sent to investigate in 1871. Other surveys followed and after being documented in the paintings of Thomas Moran and the photographs of William Henry Jackson congress was lobbied to make Yellowstone the world’s first national park. On March 1, 1872 Yellowstone was established, a conservation milestone, and it was more due to its unique thermal features than the wildlife or scenery that it is known for today.

Hot Springs



NPS Photo

Punchbowl Spring

Hot Springs are formed when water percolates through porous ground and then is heated by the earth and returns to the surface under pressure. Underground channels allow rapid circulation of water through convection currents and the rising hot water releases heat energy by evaporation or hot water runoff. Dissolved minerals in the water are deposited as it runs off and, over time, a hot spring or geyser can build a very impressive and elaborate formation around itself.



Boiling River

The Boiling River, conveniently located on my way to work, is a great place to soak. As a confirmed thermophile, I have spent a significant portion of the last six years at this magical place and others like it. Scalding hot water emerges from an underground channel and cascades into the Gardner River resulting in a delightful mix of hot and cold.

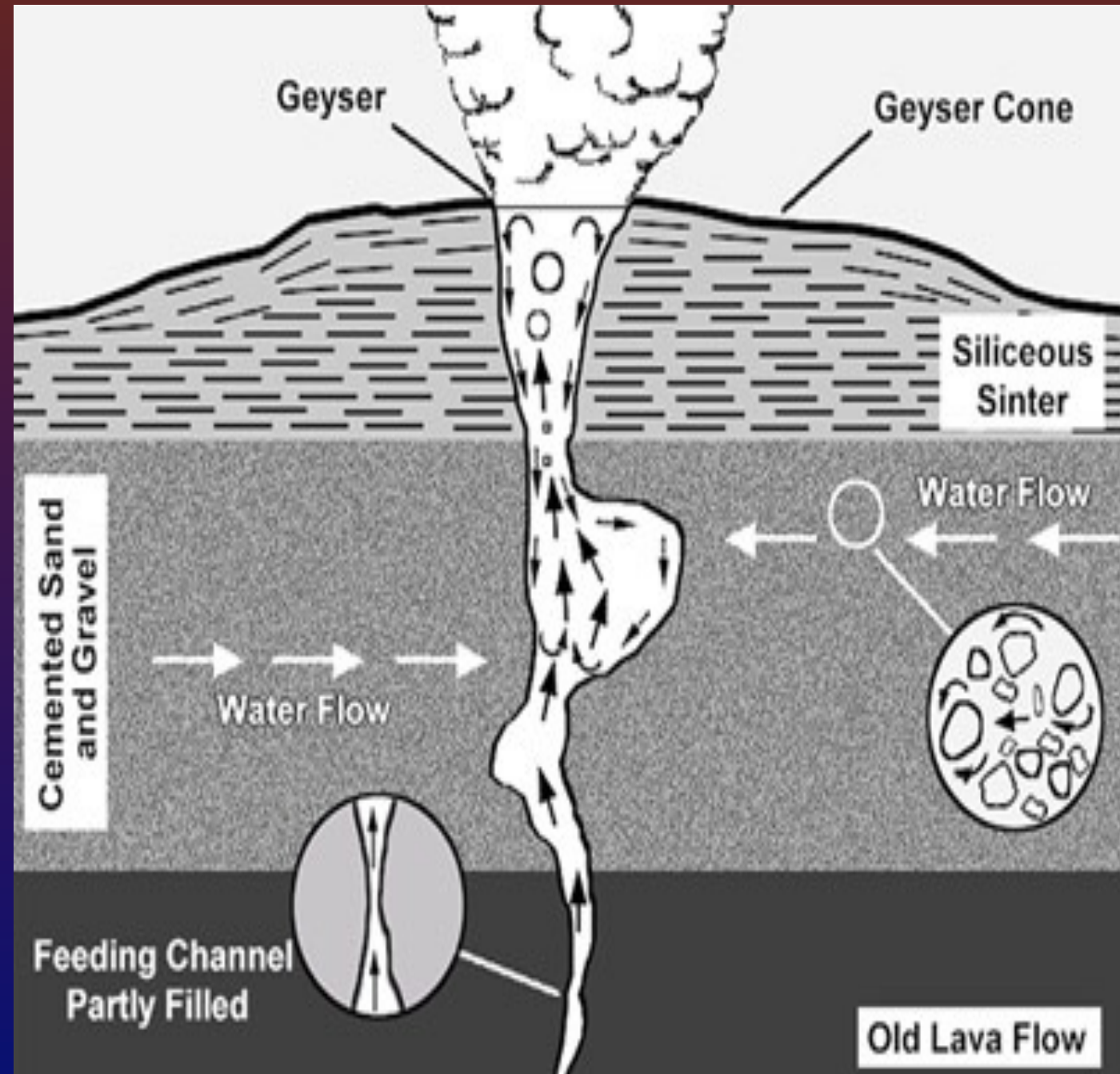


Source to my “Private Shower Soaker” near Boiling River



Geyzers

Geyzers are hot springs that erupt. Eruptions result from super-heated water underground becoming trapped in channels leading to the surface. The hottest temperatures are at the bottom of these channels but the deep water is unable to vaporize because the weight of the water above is too great. Steam bubbles rise, collecting in the channel's tight spots until they become clogged, leading to a critical point when the confined bubbles lift the water above causing the geyser to overflow. This sudden decrease in pressure at the surface causes violent boiling to occur throughout the length of the column, producing a tremendous volume of steam which forces the water out of the vent.





Old Faithful



Old Faithful Geyser no longer erupts every hour on the hour (it never did) but, it does erupt every 35-120 minutes for 1-5 minutes to a height of up to 184 ft. and is very predictable. It is arguably the most famous geyser in the world. Although all geysers are named after The Geyser in Iceland, Old Faithful has been viewed by in eruption more spectators than any other.



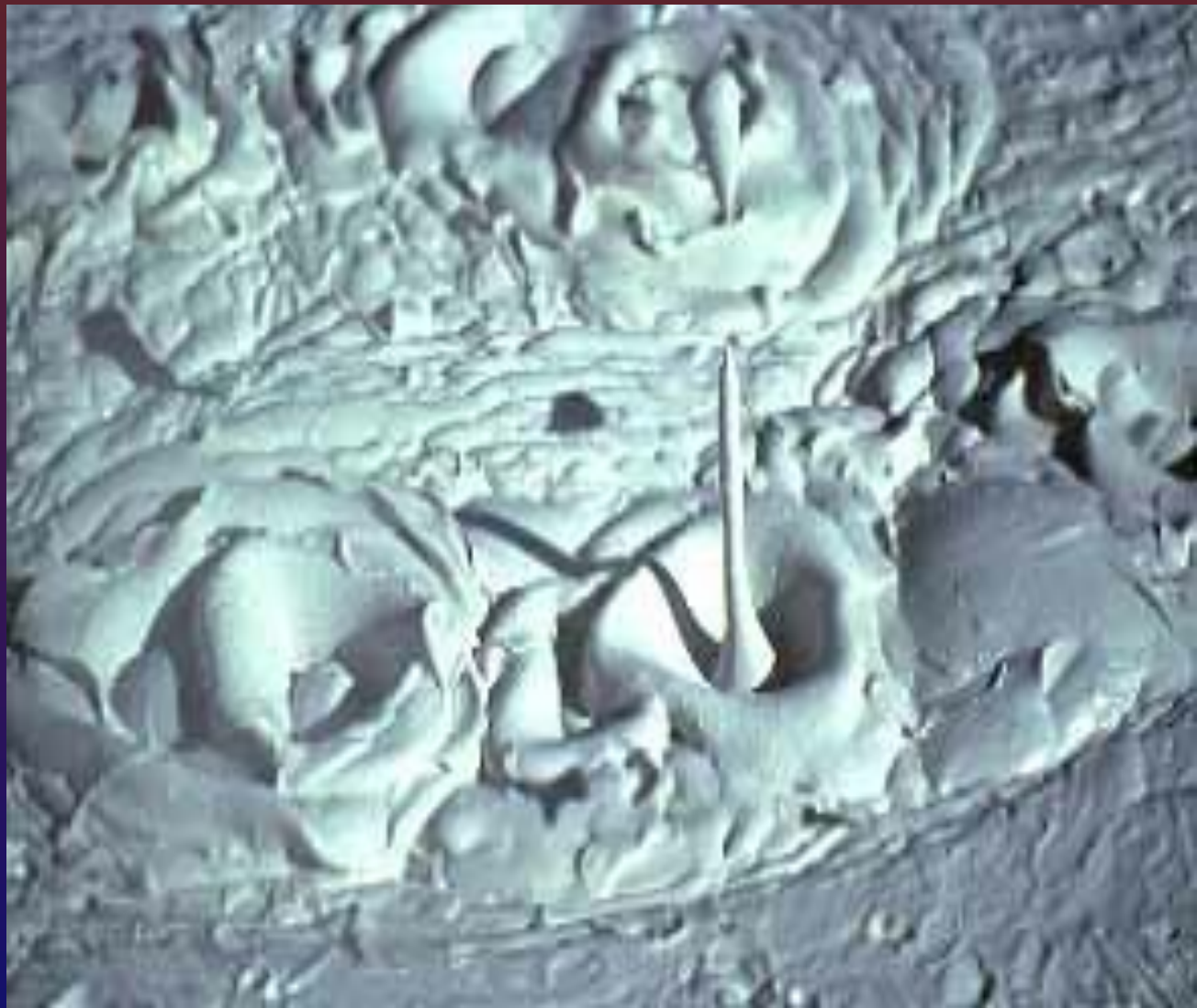
Fumaroles

Fumaroles are steam vents from springs that are very hot. Either there isn't enough water or the underground rock is so hot that it boils off all of the water so a pool is unable to form. The small amount of water that does exist is converted to steam and rises from the vent into the air. These features often produce a loud hissing or roaring noise.





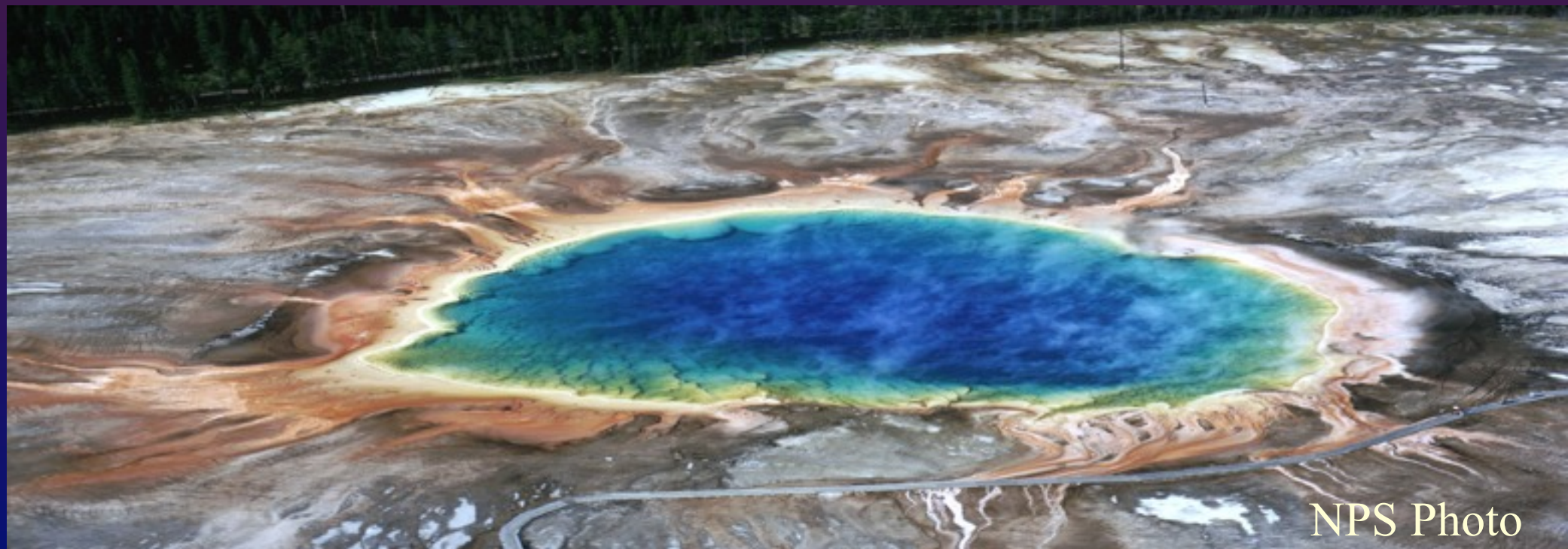
Mudpots



Mudpots are thermal features containing water saturated by sediments consisting of silica and clay dissolved from rock by sulfuric acid created from hydrogen sulfide gas. Super-heated steam rises through the mud and ground water, causing bubbles to burst and mud to spray as if it's boiling.

Life at High Temperatures

Many specialized life forms thrive in Yellowstone's geothermal environments. Bacteria, cyanobacteria and algae can live in the hottest of waters while insects and even some fish live in cooler thermal waters. The organisms are adapted to live only within a specific temperature range. Any given spring can have a wide range of temperatures: hottest near the sources and cooler at the edges resulting in an array of different of organisms living within one single spring. The brilliant colors in many of the pools are due to these life forms that have found their niche.



Grand Prismatic Spring

Grand Prismatic Spring, Yellowstone



Summary

Hot Springs	Hydrothermal Vents
Sea level, terrestrial	Marine
Photosynthesis + Chemosynthesis	Chemosynthesis
Bacteria	Bacteria + Archaea
Stable	Grown and collapse
40–90 °C	200–400 °C

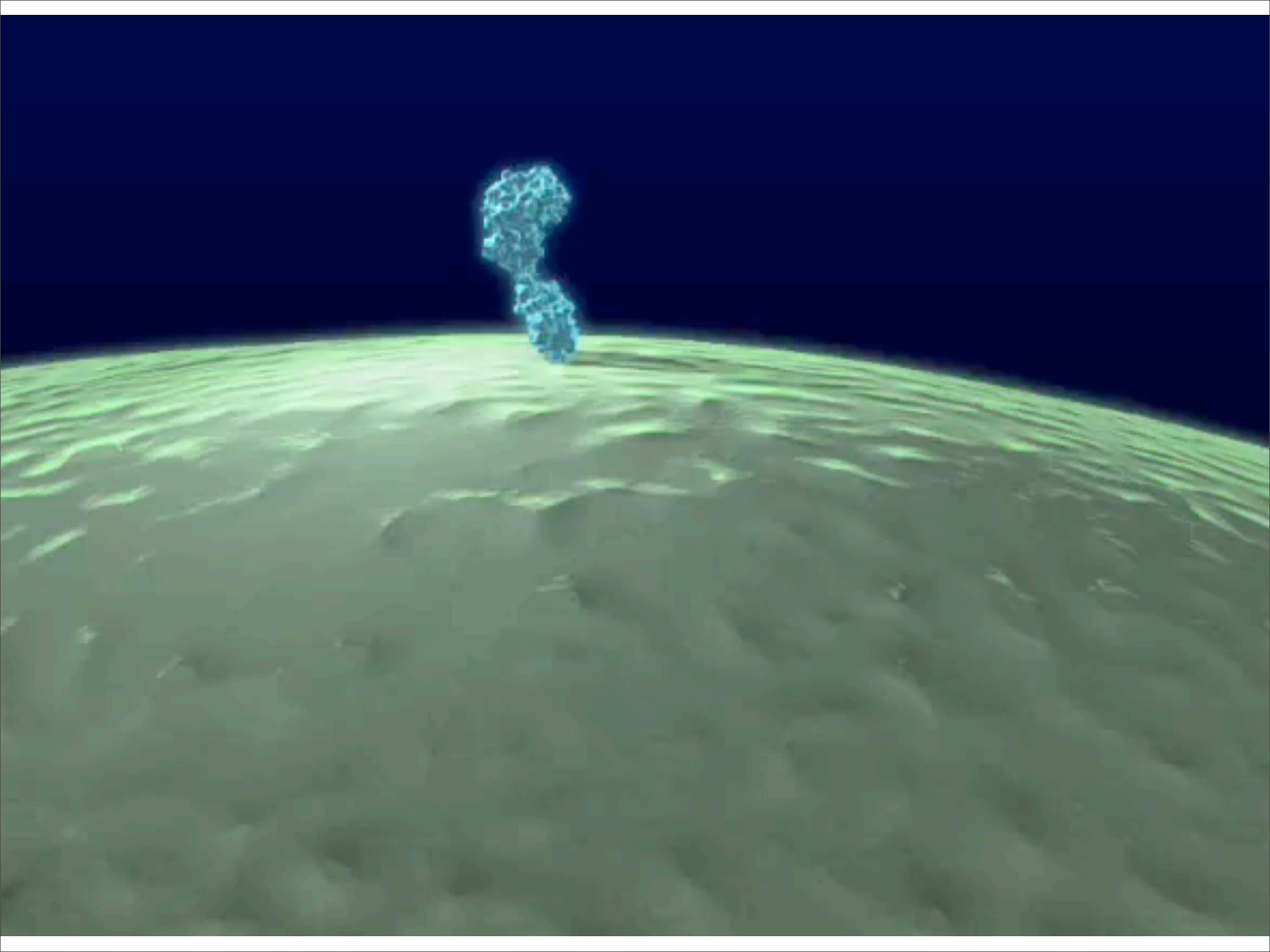
Examples of extreme

A Protein Summary

Recall that Nucleic acids are also adversely effected by extreme temps however we will only focus on proteins in this unit

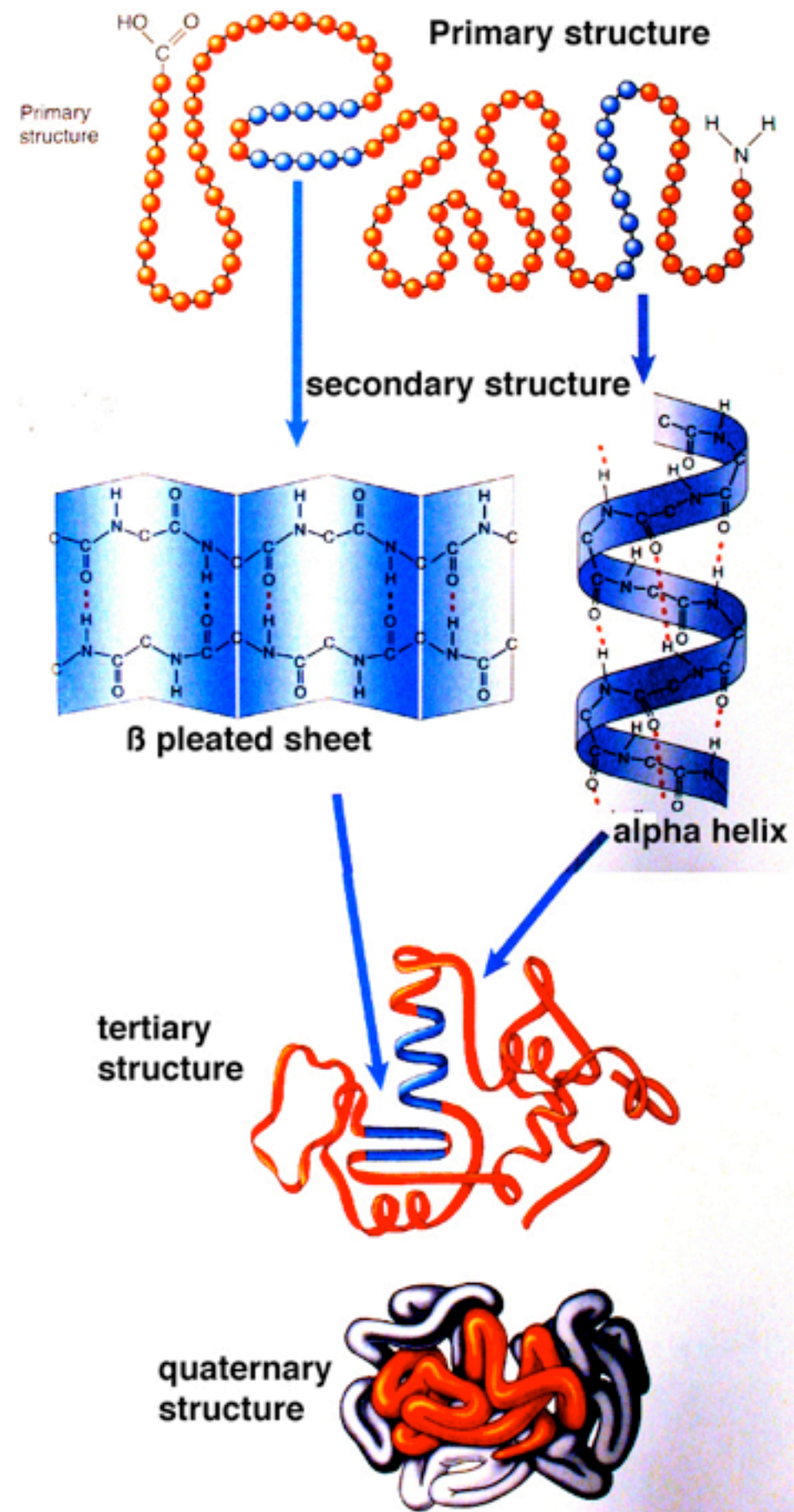
B. Protein Structure and Function

- Functions of proteins depend on their architecture.
 - This architecture is dependent upon the amino acid sequence.
- Proteins are more than just a polypeptide chain, proteins must be twisted, folded and coiled into a specific shape.
- The twisting, folding and coiling is held in place by a variety of bonds between the groups on the amino acids.
- Proteins generally take one of two shapes:
 - Round... *globular proteins*
 - Linear... *fibrous proteins*
- In almost every case the function of a protein depends on its ability to recognize and bind with some other molecule.



I. Four Levels of Protein Structure

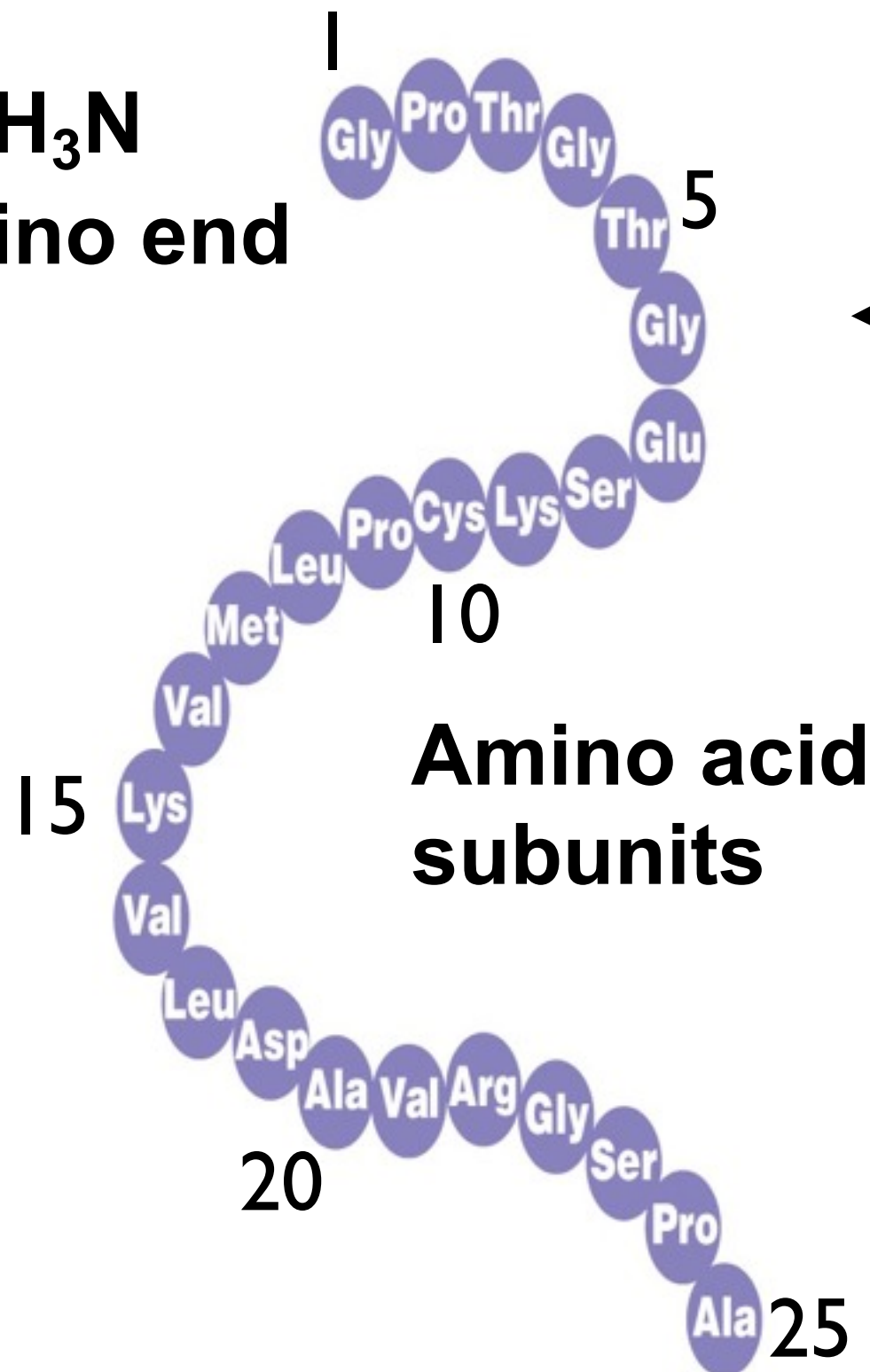
- With a goal to understand a protein's function, it's productive to begin by dissecting its structure.
- All proteins have levels of structure: *primary*, *secondary* and *tertiary*. Some have a fourth level, *quaternary*.



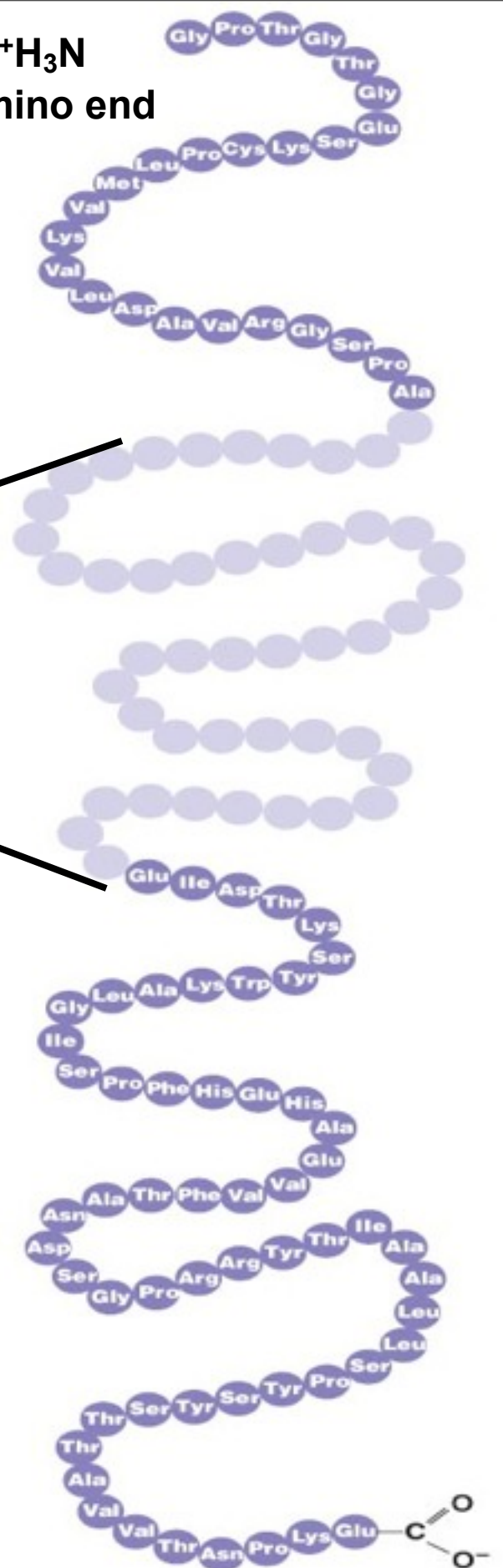
Primary Structure

Linear Chain of Amino Acids

$^+\text{H}_3\text{N}$
Amino end



$^+\text{H}_3\text{N}$
Amino end

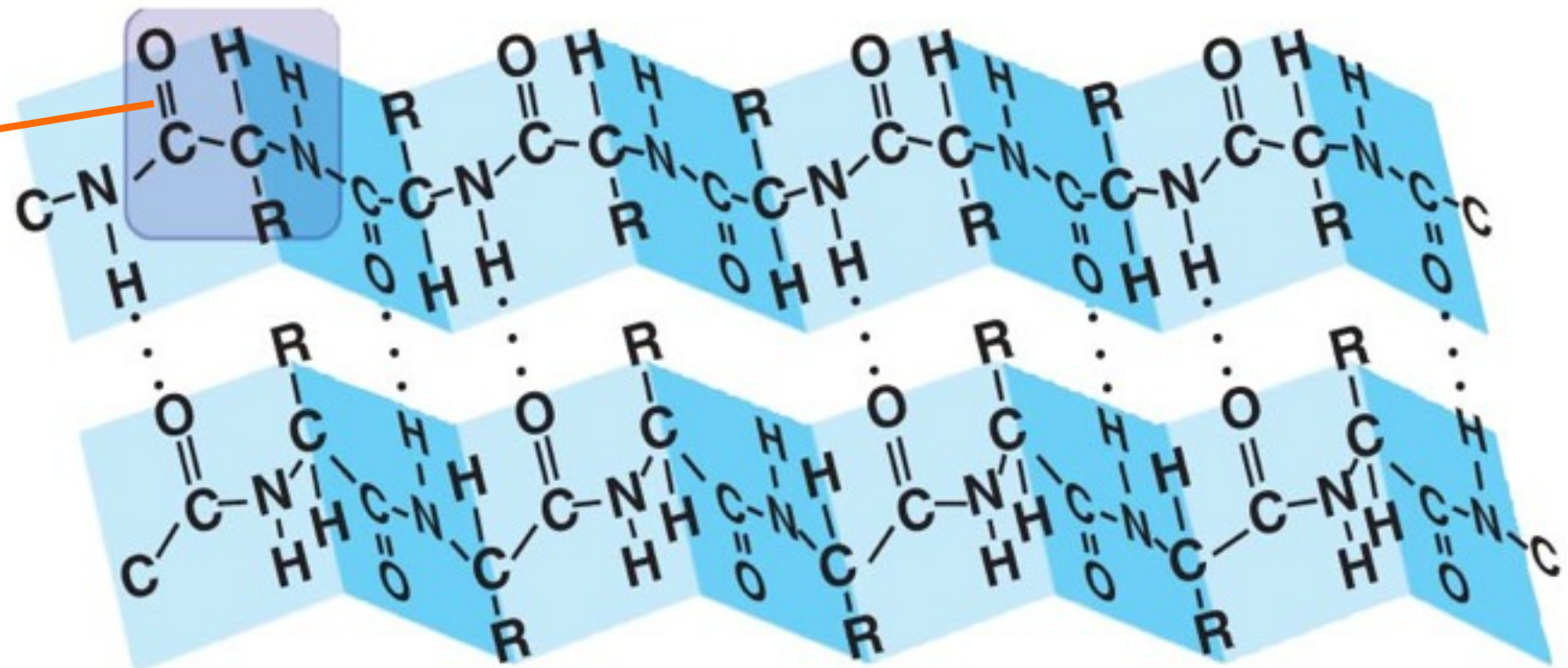


Carboxyl end

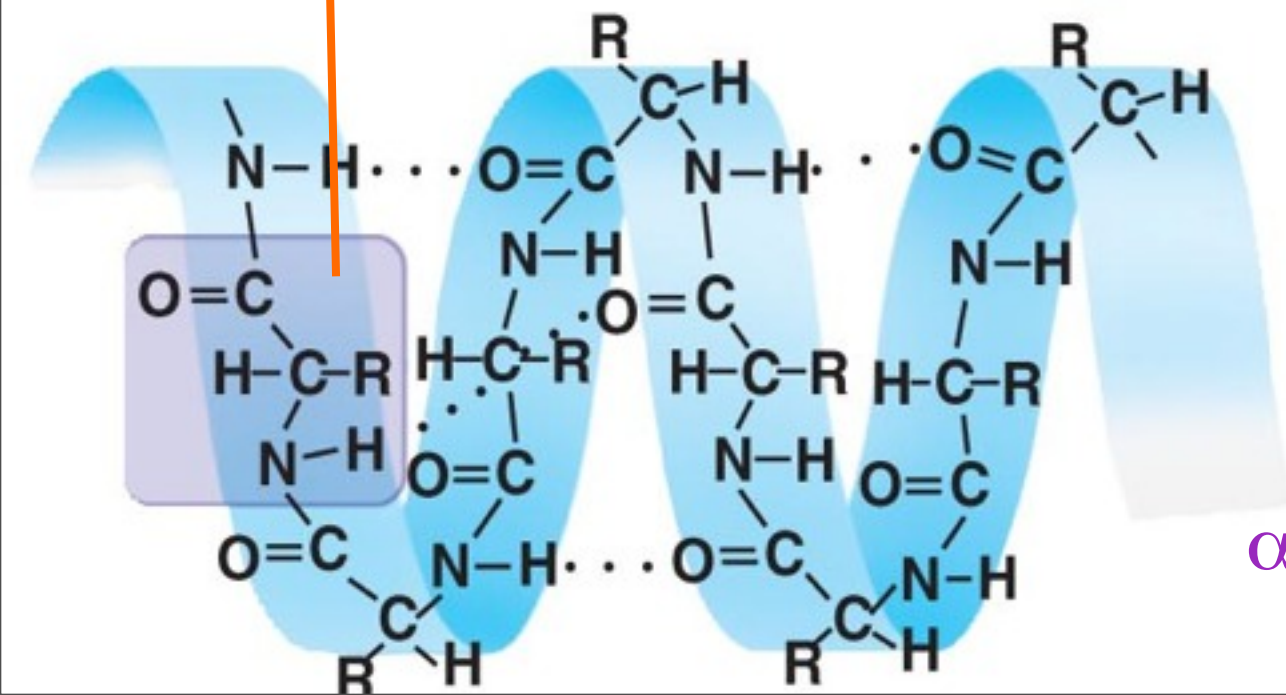
Secondary Structure

Regions stabilized by hydrogen bonds between polypeptide chains

Examples of
amino acid
subunits



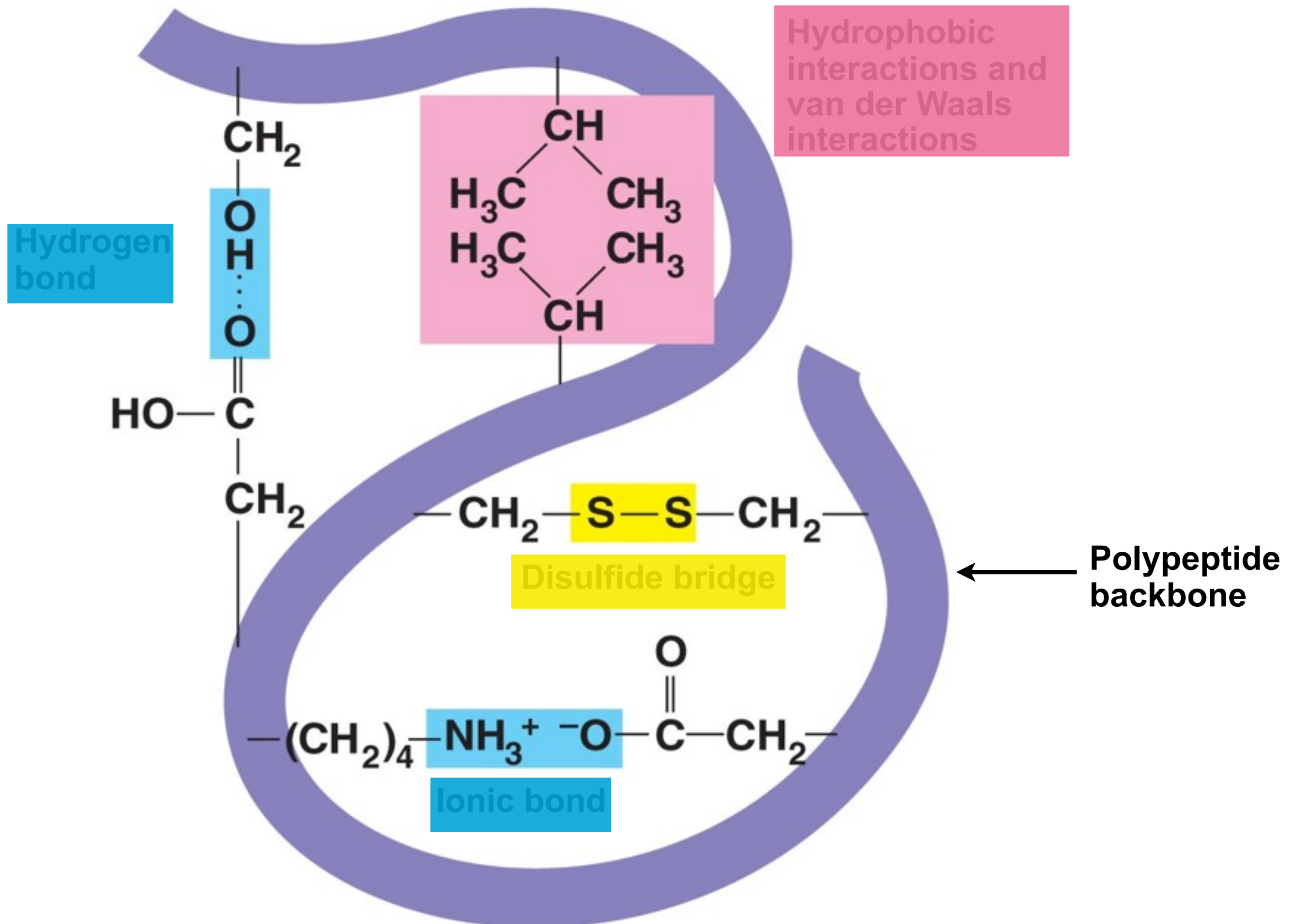
β pleated sheet



α helix

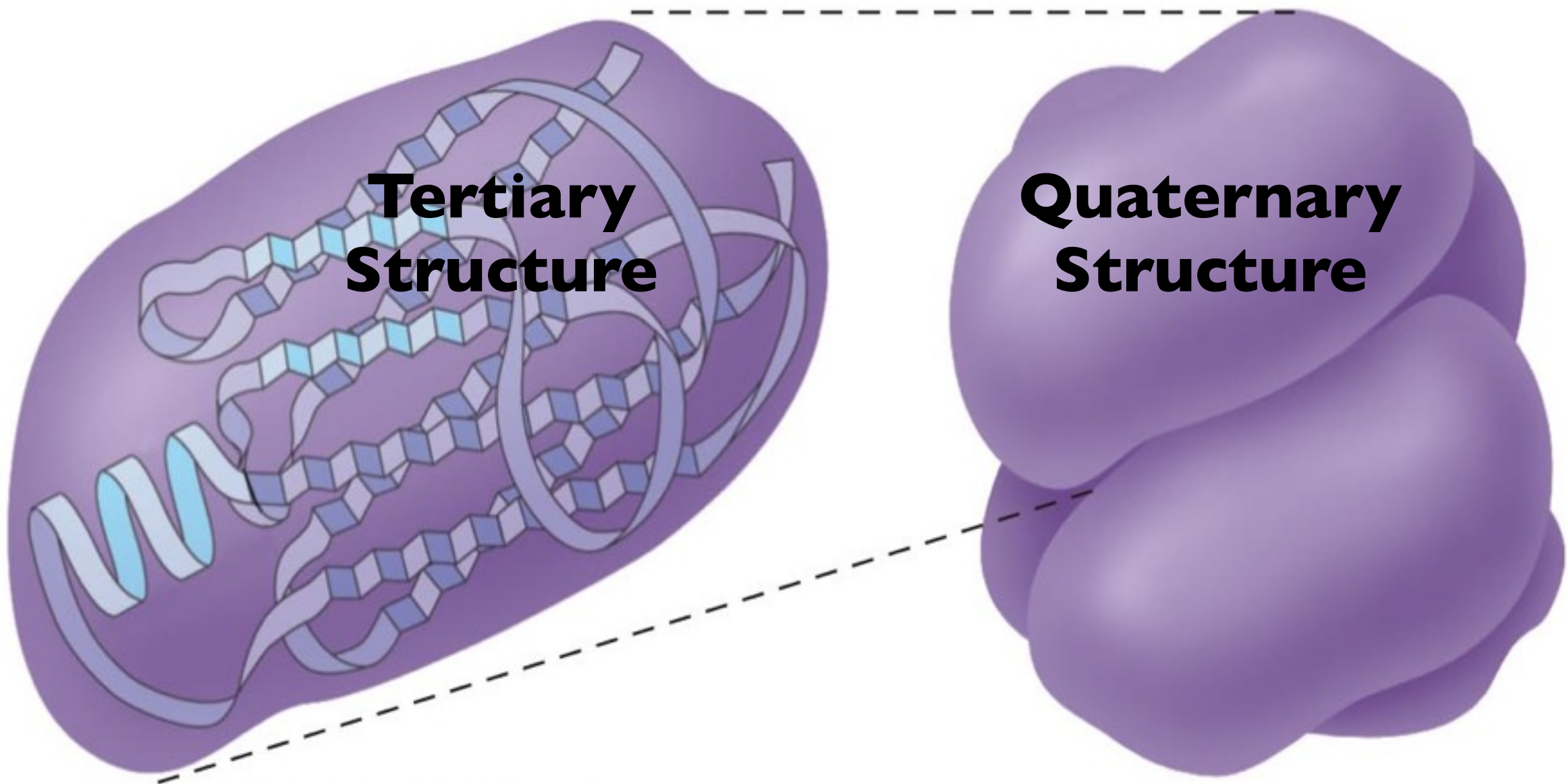
Tertiary Structure

Overall 3-D Shape



Tertiary Structure

Some tertiary proteins come together and form larger proteins



Quaternary Structure

Association of multiple polypeptides forming a functional protein

Polypeptide
chains



Collagen

**One of many examples
of human's copying
life's architecture**



Another Look at Protein Folding



Protein Denaturation

Protein Denaturation