Life Without Light: Chemoautotrophically Based Cave Biology

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• In 1890, Sergei Nikolaevich Vinogradskii (or Winogradsky) proposed a novel life process called **chemosynthesis**.

• **Chemosynthesis** is the biological conversion of one or more carbon molecules (usually CO$_2$ or CH$_4$) and nutrients into organic matter using the oxidation of inorganic molecules (e.g. H$_2$ gas, H$_2$S) or CH$_4$ as a source of energy, rather than sunlight, as in **photosynthesis**.
The publication of Emil Racovita’s work *Essai sûr les problèmes Bioespéleologiques* (1907) laid the foundations for *biospeleology* (the study of organisms that live in caves) as a separate scientific discipline.
Romania
Carbonic acid speleogenesis

- \( \text{H}_2\text{O} + \text{CO}_2 \leftrightarrow \text{H}_2\text{CO}_3 \)

- \( \text{CaCO}_3 + \text{H}_2\text{CO}_3 \leftrightarrow \text{Ca(HCO}_3\text{)}_2 \)
  
  insoluble  soluble
• Permanent darkness

• No plant life

• Small amounts of food coming from the surface

• Very few life forms present
Deep Sea Vents
Movile Cave, 1986
Movile Cave
upper dry level

Main passage

Lake

Entrance shaft

dry part of the cave

Air bell 2

Air bell 1

Lake

submerged part of the cave

Sea level
$^{137}$Cs in surface soil and cave sediments (pCi/g)
April 1992
Movile Cave

0.5 ± 0.04

$^{137}$Cs in sediment (pCi/g)
April 1992
Radu Spring

0.2 ± 0.02

< 0.02
Stable isotopes: $^{12}\text{C} (99\%), \; ^{13}\text{C} (1\%)$

The number of neutrons varies

$$\delta^{13}\text{C}_{\%} \text{ vs [std.]} = \frac{R_{\text{sample}} - R_{\text{std}}}{R_{\text{std}}} \times 1000$$

Isotopic Fractionation: enzymes select for light isotopes:

$\text{CO}_2 (\delta^{13}\text{C} - 7\%) \rightarrow \text{Sugar} (\delta^{13}\text{C} - 27\%)$

RuBisCO

Fractionation of -21\%
Food Web Analysis using Stable Isotopes

“We are what we eat + 1.5 ‰”

\[
\begin{align*}
\text{Grass} & \rightarrow \text{Deer} & \rightarrow \text{Wolf} & \rightarrow \text{Flees} & \rightarrow \text{Mites} \\
-27\% & \rightarrow -25.5\% & \rightarrow -24\% & \rightarrow -22.5\% & \rightarrow -21\% \\
\end{align*}
\]

* $\delta^{13}C$ values
del 13C vs del 15N

Cryptops sp., Cryptopidae, Chilopoda
LIGHT ENERGY

EPIGEAN PHOTOLITHOTROPHIC PRODUCERS

SOIL COMPARTMENT
Start of the decomposition of organic matter by the soil fauna and microbiota
Consumers

migrations

SUBTERRANEAN SUPERFICIAL ENVIRONMENT
Consumers

migrations

DEEP SUBTERRANEAN ENVIRONMENT
Detritivores Carnivores

Consumers

CHEMOLITHOAUTO TROPHIC PRODUCERS

CHEMICAL ENERGY
Ongoing Research Projects:

- Geographic extent of the thermal aquifer
- Descriptions of new species
- Origins of the subterranean fauna
- Ecosystem studies
- Microbiology:
  - Sulfur and Methane Oxidation and Nitrification
  - Microbial Community Studies
  - Symbioses
**Sulfuric Acid Speleogenesis**

\[ \text{H}_2\text{S} + \text{O}_2 \leftrightarrow \text{H}_2\text{SO}_4 \text{ (Sulfuric acid)} \]

**A** \[ \text{CaCO}_3 + \text{H}_2\text{SO}_4 \leftrightarrow \text{CaSO}_4 + \text{H}_2\text{CO}_3 \]

Limestone \hspace{1cm} Gypsum (soluble) \hspace{1cm} Carbonic Acid

**B** \[ \text{CaCO}_3 + \text{H}_2\text{CO}_3 \leftrightarrow \text{Ca(HCO}_3\text{)}_2 \]

Limestone

*Double dissolution: two CaCO$_3$ removed for each H$_2$S oxidized*
Chemoautotrophically Based Cave Ecosystems

- Romania: Movile Cave
- Italy: Frasassi Caves
- Israel: Ayyalon Cave, En Nur Spring
- USA: Lower Kane Caves
- Mexico: Cueva de Villa Luz, Tabasco
- Libya: Cave at Bengazi
The Frasassi caves are the most studied hypogenic caves in Italy. The caves consist of a network of ramifying, mainly sub-horizontal passages in which wide rooms (up to \( \sim 10^6 \, \text{m}^3 \)) alternate with smaller tubes.
“Snotites”

pH = 0.0 – 0.3
Corroded Limestone
superficie ed ingressi grotte

\[ \delta^{15}N \] vs \[ \delta^{13}C \]

- rami sulfurei
- zona mucoliti
Tabgha – En Nur Spring
Israel
Ayyalon Cave
Israel
Cueva de Villa Luz, Tabasco, Mexico
Benghazi
Libya
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