

Solubility

What is it? And who cares?

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Solubility is the ability to dissolve;
for one substance to physically
completely disappear into another.

Examples of dissolution include:

**Salt into water
to make the aqueous
solution called brine.**

**Platinum into gold
to make “white” gold.**

**Oxygen in nitrogen
to make air.**

Solutions can be between

2 liquids (water and alcohol)

2 solids (platinum and gold)

2 gases (oxygen and nitrogen)

or any combination of these.

Solutions can be **complete** like air.

Or they may be **limited** like brine.

It is possible to load water with enough salt that no more can dissolve. In that case the solution is **saturated**.

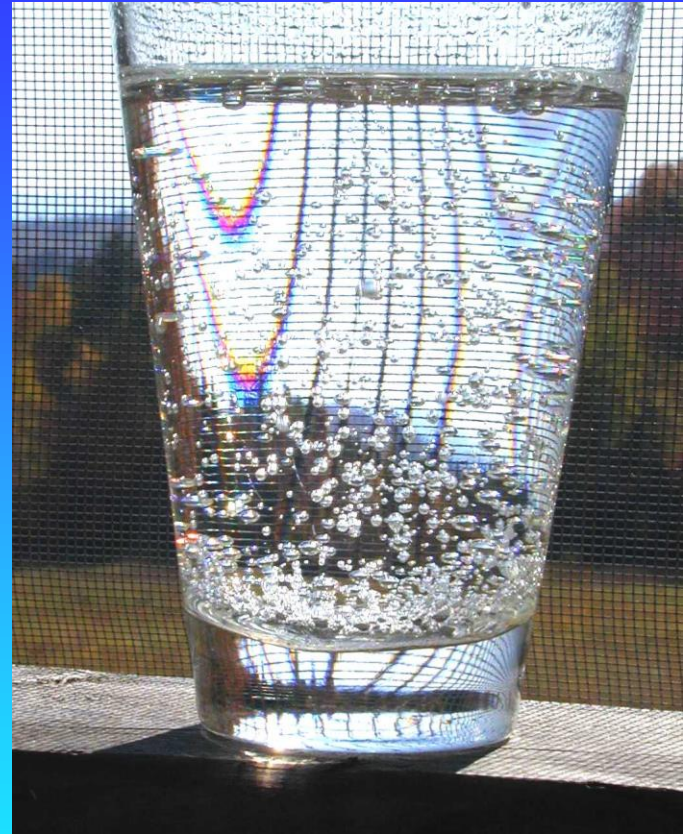
The amount of material required to reach saturation is the **solubility**.

Solubility impacts our environment,
so **we** should care!
Especially about the changes!!!!

Solubility can change with **temperature**,
or **pressure**, or **solvent**.

Rain and snow happen when H_2O
becomes less soluble in air during cooling.

Solubility change with **pressure** is illustrated by the effervescence of CO_2 from soda.



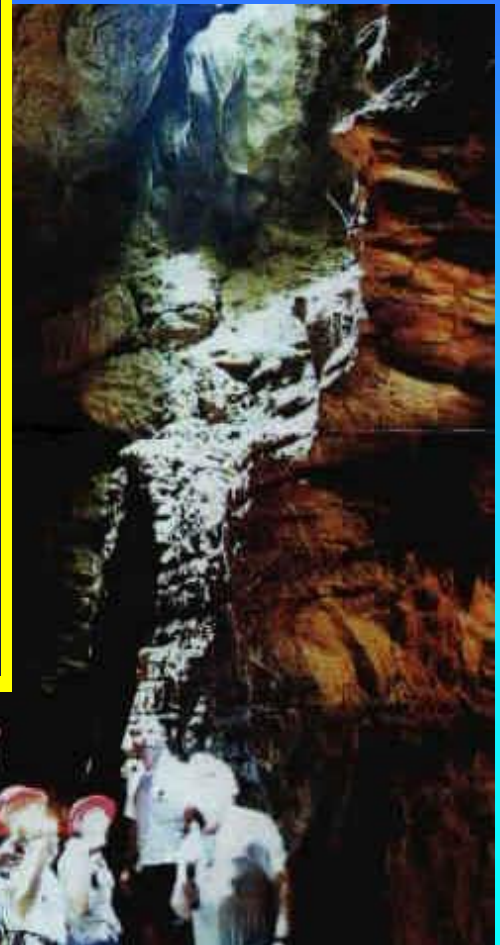
CO_2 is more soluble at the high pressure of bottling. It bubbles out of solution when the bottle is opened to atmospheric pressure.

The role of the solvent is well illustrated in cave formation.

Water in the ground can dissolve CaCO_3 . Limestones in wet climates are vulnerable to dissolution into ground water with the result that caverns can form.



Venado Cave
Central America



Factors influencing the formation of caves:

Soluble carbonate bedrock.

Ready supply of solvent (ground water).

Flow of the solvent and replacement with fresh unsaturated solvent.

The solvent may be more potent if organic acids from vegetation raise solubility of CaCO_3 .



This Puerto Rican cavern opens onto lush tropical surroundings which may have aided its formation.

Dissolving the cavern in the ground is not always the whole story with caves.



This cavern is redepositing carbonate where it was formerly dissolved. **Speliothems** (cave formations) result.



The transition from dissolving to depositing often signals a change in the solvent (ground water) supply.

The flowstone stalactites that are beginning to form here are a consequence of saturated ground water reaching an aerated cavern. As water evaporates in the dry cave, carbonate is deposited because the water becomes too concentrated in carbonate to hold it in solution.

The transition from a water-filled cavern dissolving the hole and a dry cave depositing speliothems signals water supply change.

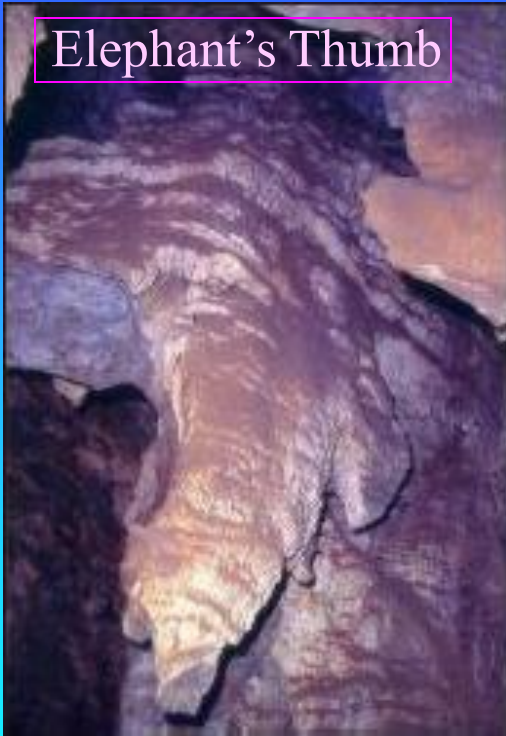
This change can be structural, for example by drainage diversion.
Or it can be by change out of a wet glacial climate.



Carlsbad Cavern, N.M. in the desert southwest US is now refilling after a period of dissolution during a wetter climate.

Speliothems are often of more interest to the cave explorer than the fact that there is a cave there at all - or that a history of climate change may be recorded.

Elephant's Thumb

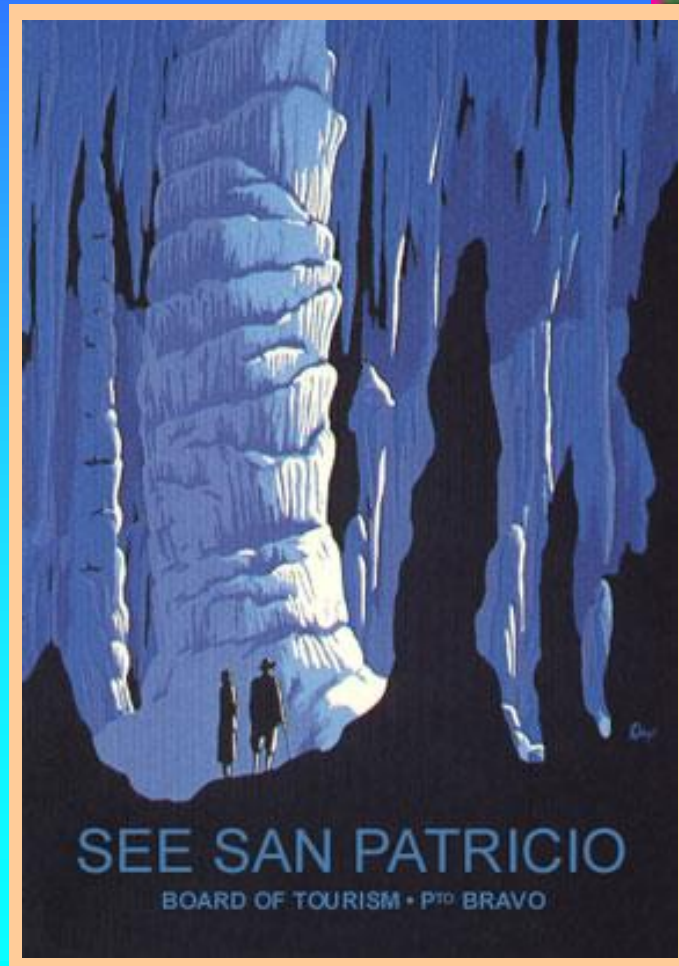


Carlsbad Cavern



Interest in speliothems can border on fantasy. The columns in Carlsbad Cavern served as prototype for the scenery in this travel poster for an imaginary destination.

Capture that interest in your students if at all possible.



It may not be dinosaurs but it does hold some attention.

There is a series of man-made caverns not far from Carlsbad Cavern near Carlsbad, NM. These caverns are much deeper underground, excavated in Permian salt.





This is a completed cavern in the salt. The salt has been here since the Permian, remaining undissolved and undisturbed.

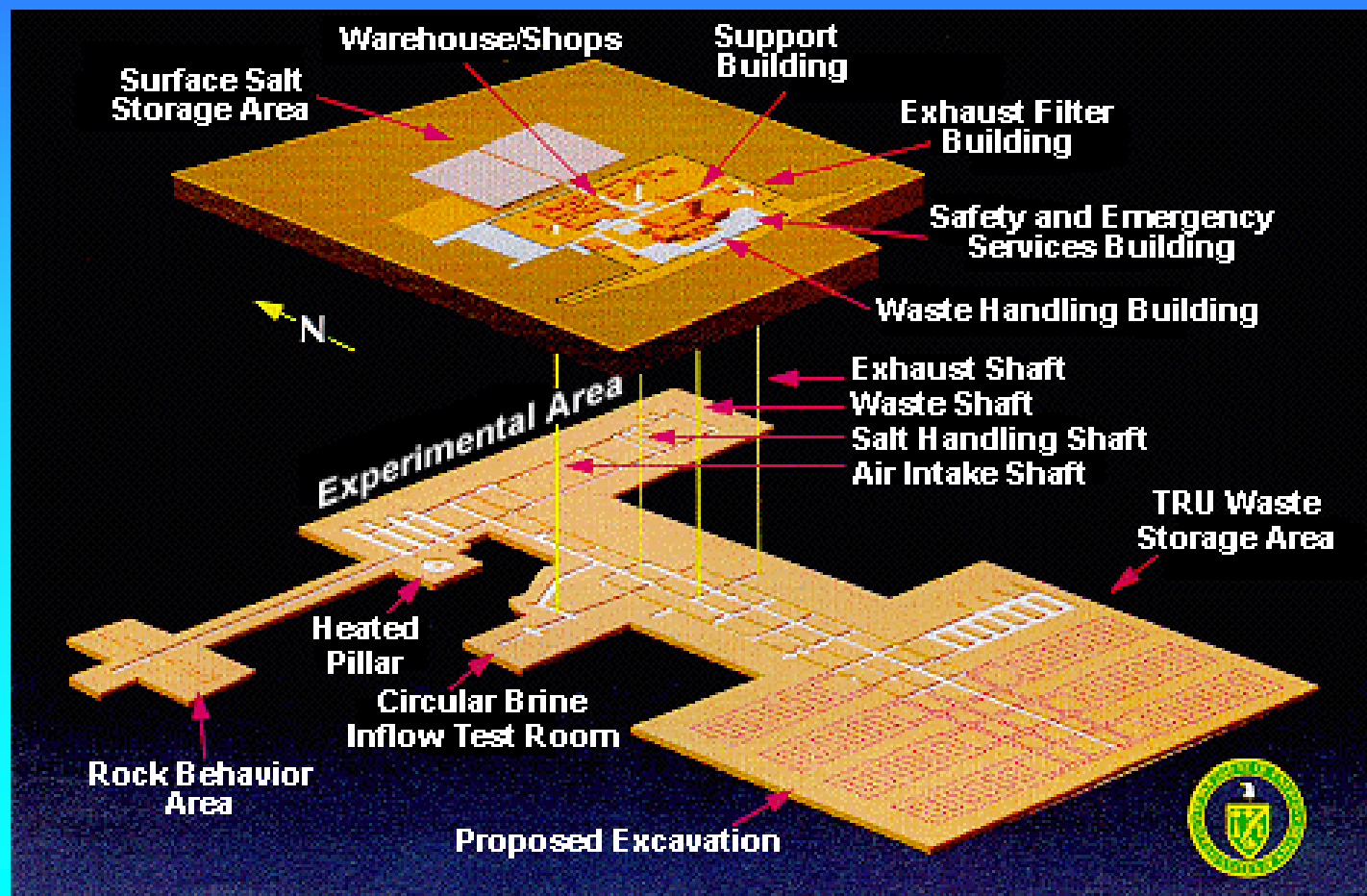
These caverns are under this DOE facility:



Waste Isolation Pilot Plant

“The Waste Isolation Pilot Plant (WIPP) in New Mexico is designed to demonstrate the safe and permanent disposal of transuranic waste in a salt bed more than 2,000 feet underground.

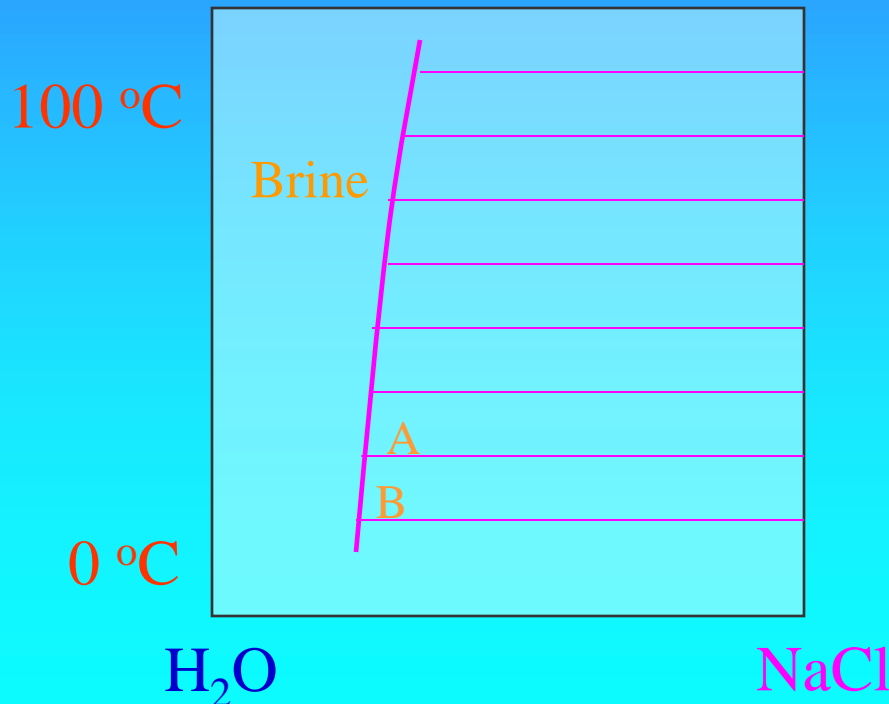
If the demonstration is successful, WIPP will become a disposal site for transuranic waste.” [DOE]

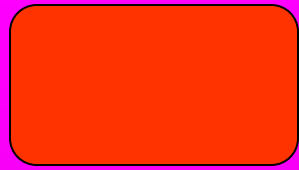


Why?: If the demonstration is successful...

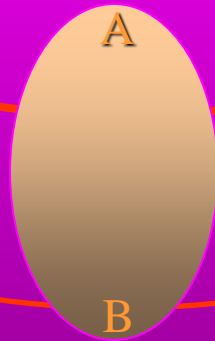
What could go wrong with a salt layer that has been stable and undissolved for a quarter billion years?

**Temperature
dependence**
to the solubility
of rock salt
(halite) NaCl.



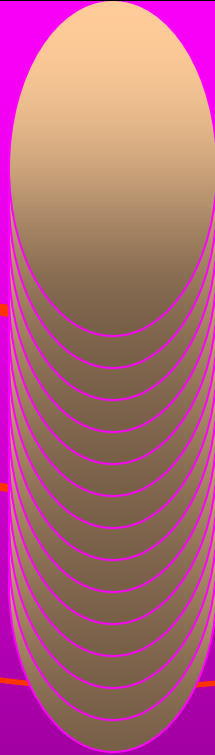
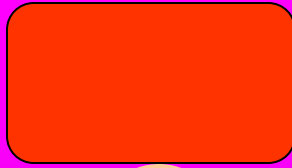


Cavern in salt with radwaste
which heats surroundings



Brine pocket in thermal gradient.
Warm A richer in salt than cool B.

Transfer of salt in pocket
from high concentration A
to less concentrated B.



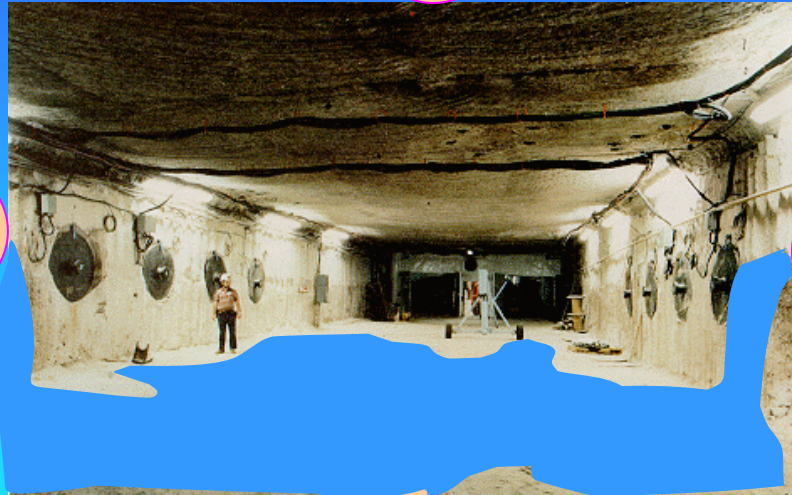
Transfer of salt in solution
from A to B causes
more salt to dissolve at A
and salt to precipitate at B.

**The brine pocket migrates
to the radwaste storage
cavern!**

Radwaste beware!!

Brine pockets track to the radwaste cave as heat-seeking creepers.

Brine released to area of radwaste cannisters.



Brine is very corrosive and cannisters attacked.

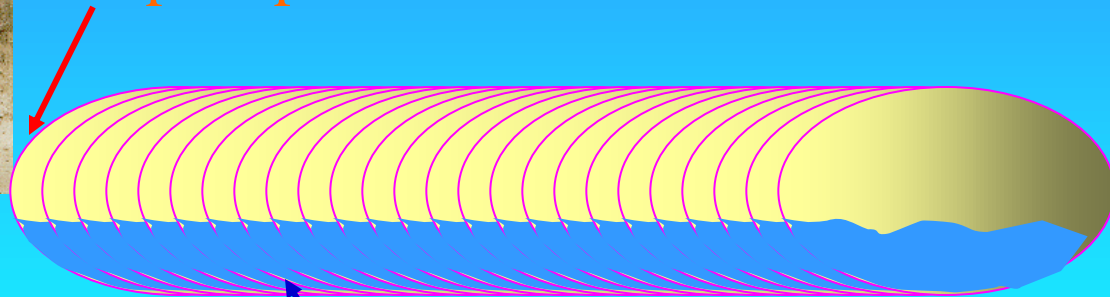
Major league **OOPS!**

But wait, it's worse than that.

Imagine a radioactive brine pocket from a corroded cannister gets into the salt with some trapped air.



This end is warmer so air evaporates and dries the brine, causing salt to precipitation at the radwaste end.



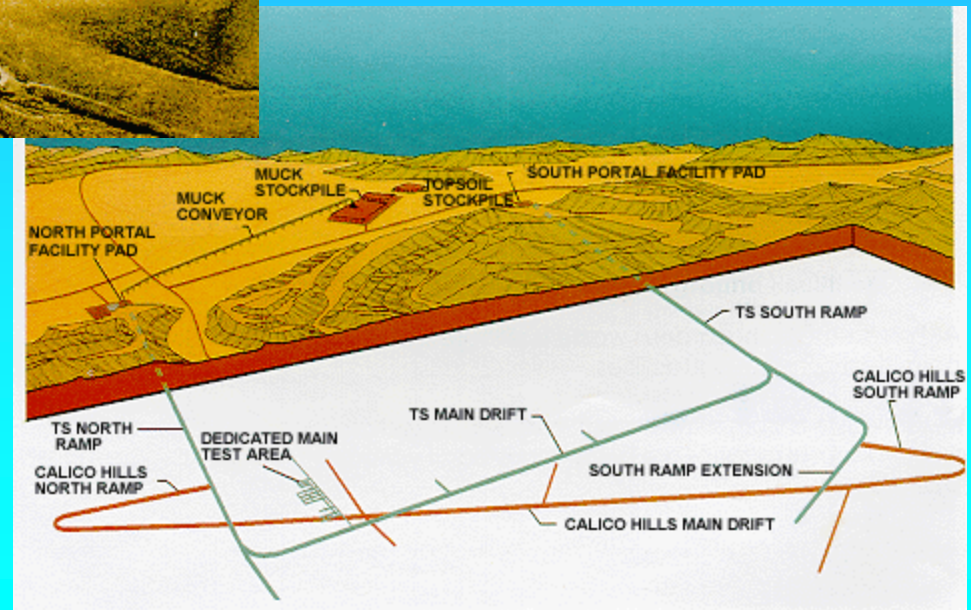
This end is cooler so the air precipitates moisture, diluting the brine and dissolving salt.

Presto, nearly perfect dispersal of radwaste achieved.

Storage in the desert **above the water table** seems an attractive alternative, and this is the case for Yucca Mt., Nevada.



Research and development is underway to explore its long-term stability.

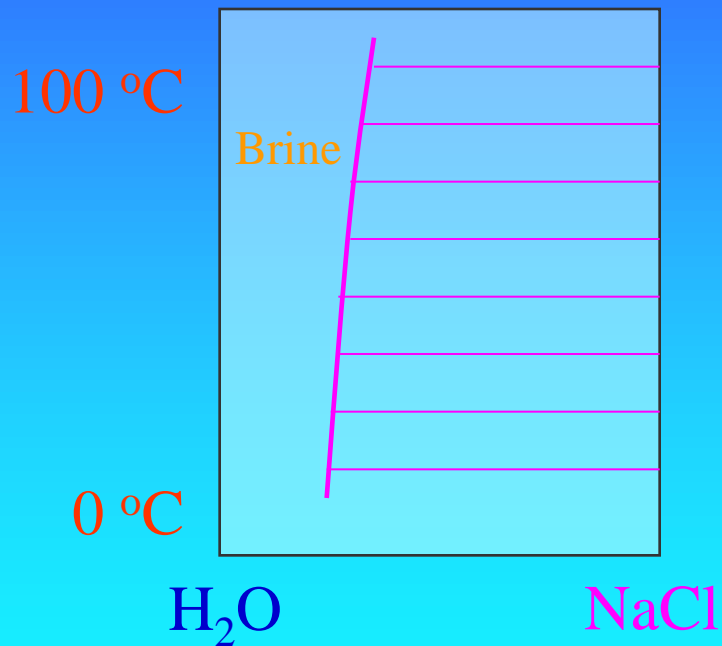


The nearby Nevada test site is already being used to store low-level waste in old nuclear explosion craters.



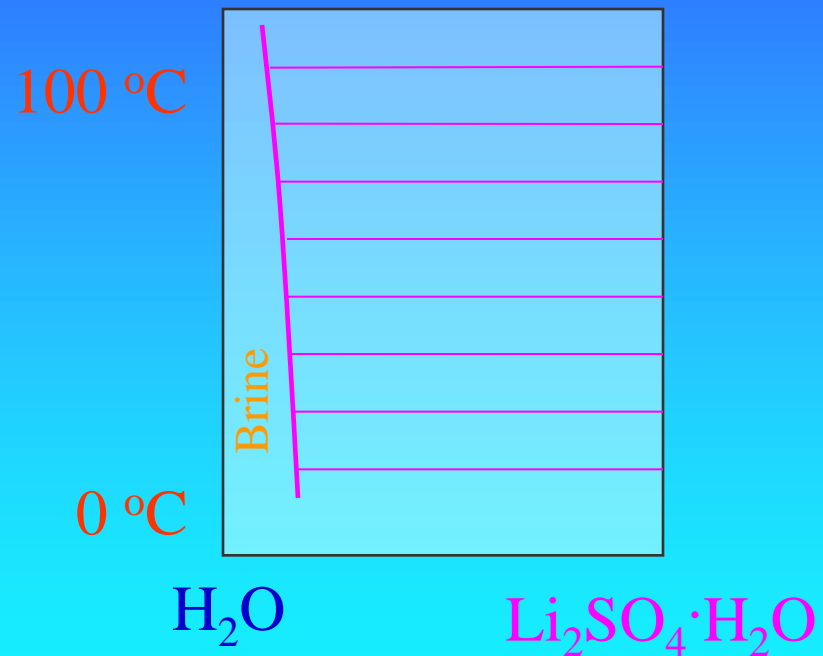
There is another possible strategy for the WIPP site in salt:

The problem

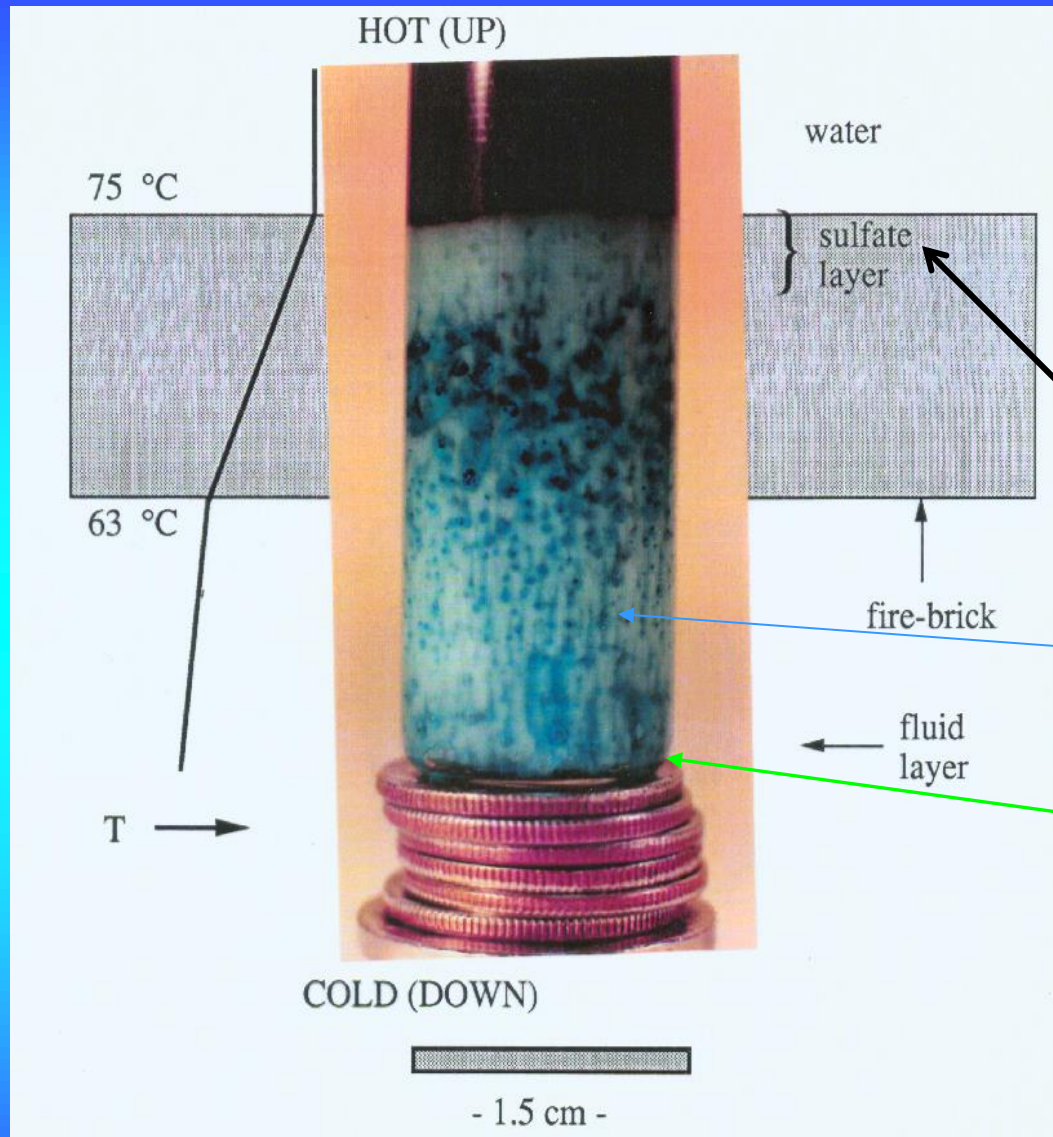


Prograde solubility

The solution



Retrograde solubility



Experiment:

10 days

Thermal gradient

$\text{Li}_2\text{SO}_4 \cdot \text{H}_2\text{O}$ + brine

Results:

Compact sulfate layer

Migration of brine
pockets away
from hot end

Collection of brine layer

Brine moves
in cold direction
when solubility
retrograde!

Migration process real!

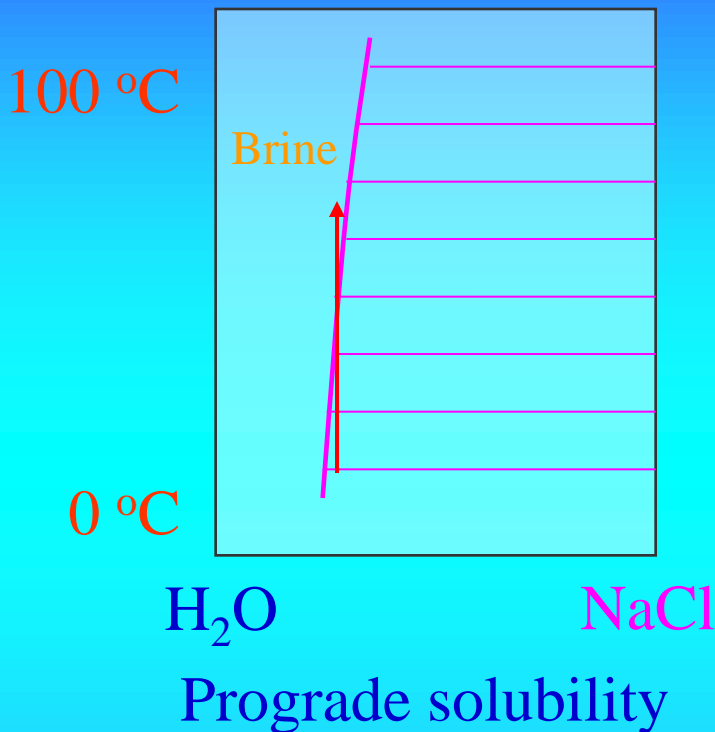
Use backfill with low, retrograde solubility at WIPP



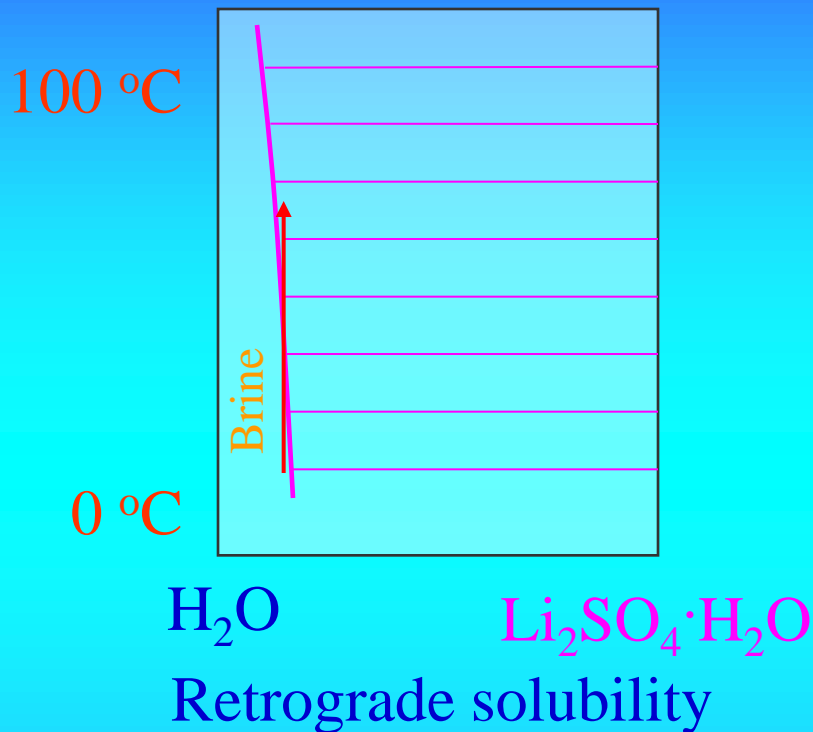
$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ [gypsum] realistic material for the backfill.

Possible Class Demonstrations:

Retrograde solubility a non-intuitive concept



Over-saturated solution
dissolves salt when
heated and becomes clear.



Under-saturated solution
precipitates when heated
and becomes clouded.

Retrograde solubility explained by hydration shells forming at the molecular level when Li^+ or Ca^{++} enter solution.

Take away points:

Solubility changes in cave formation water supply controlled even though solubility retrograde.

Solubility issues in nuclear waste storage at WIPP temperature controlled.

Retrograde solubility real and potentially useful in mitigating nuclear waste hazards.

Next time we can do solubility in the Earth's core.