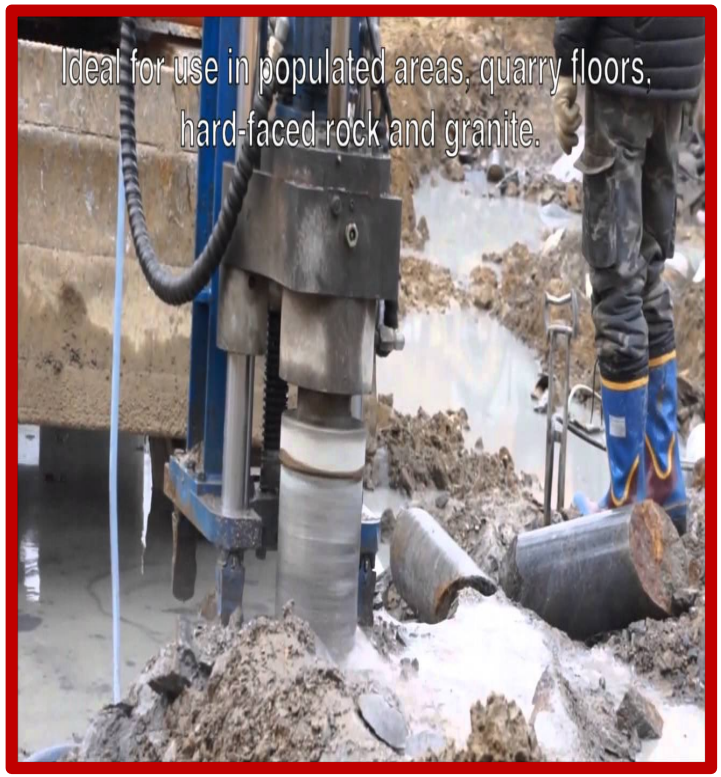
Lifetime Learning Institute, October 24, 2021



21FA29 - Drill Baby Drill: A Look at the Major Tool Used to Interpret What's Under the Earth

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PRETEST

- **Ground Wells are used for three main purposes.**

  A. Putting something into the ground

  B. Taking something out of the ground

  C. Both putting something in AND taking something out

1. What types of wells are used for A?

- ✓ **What is put into the earth using your answer to 1?**

2. What types of wells are used for B?

- ✓ **What is taken out of the earth using your answer to 2?**

3. What types of wells are used for C?

- ✓ **What is put in and take out the earth using your answer to 3**

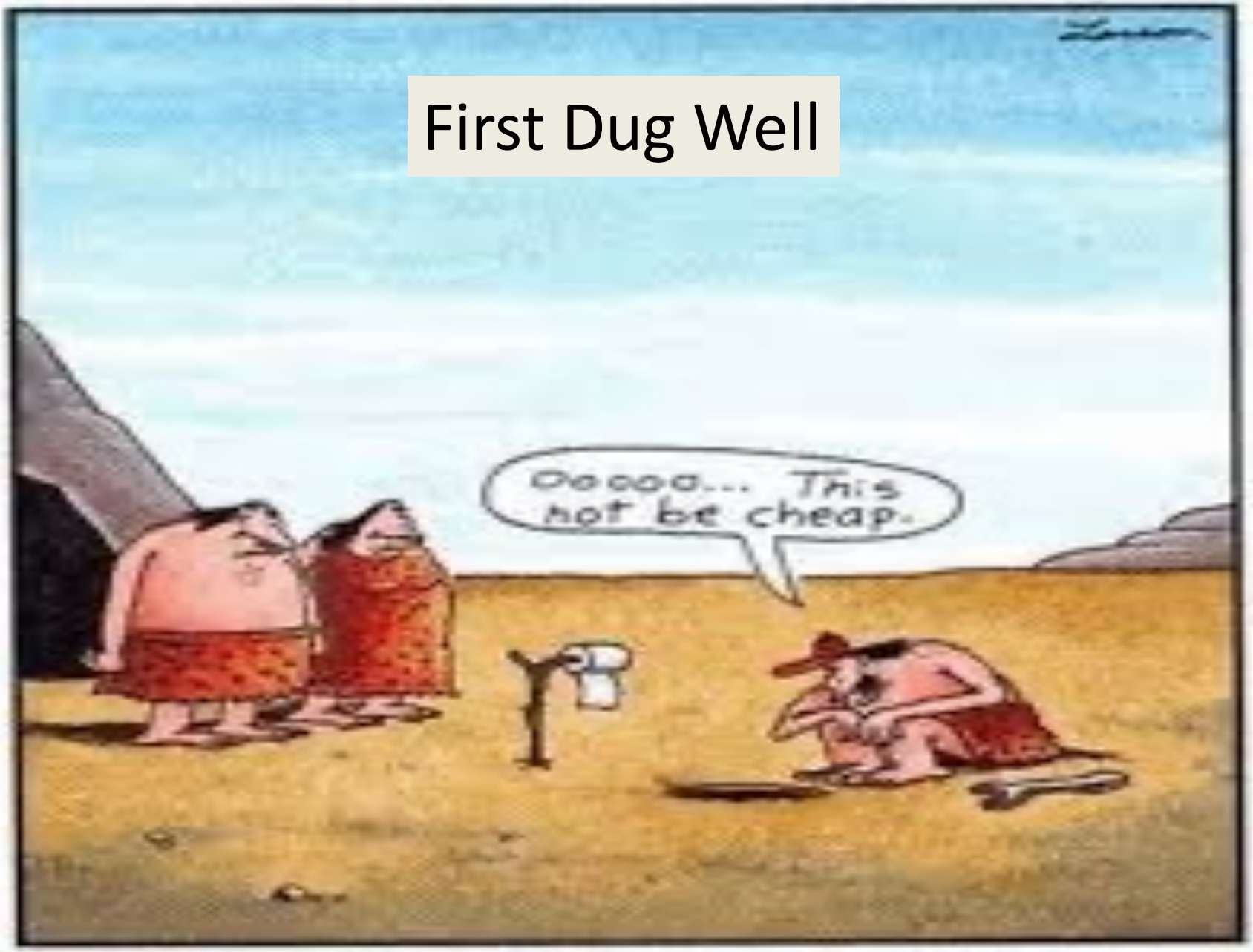
What We Will Talk About

- Types of Wells
  - ✓ Injection Wells
  - ✓ Extraction Wells
    - ➢ Core Drilling in Rock
  - ✓ Fracking
- Fracking + and --
- The Earth's Interior:
  - ✓ What's our best guess?
  - ✓ What are our "best guessing" tools?
- Core Drilling in Ice
- Latest on Climate Change

TYPES OF WELLS

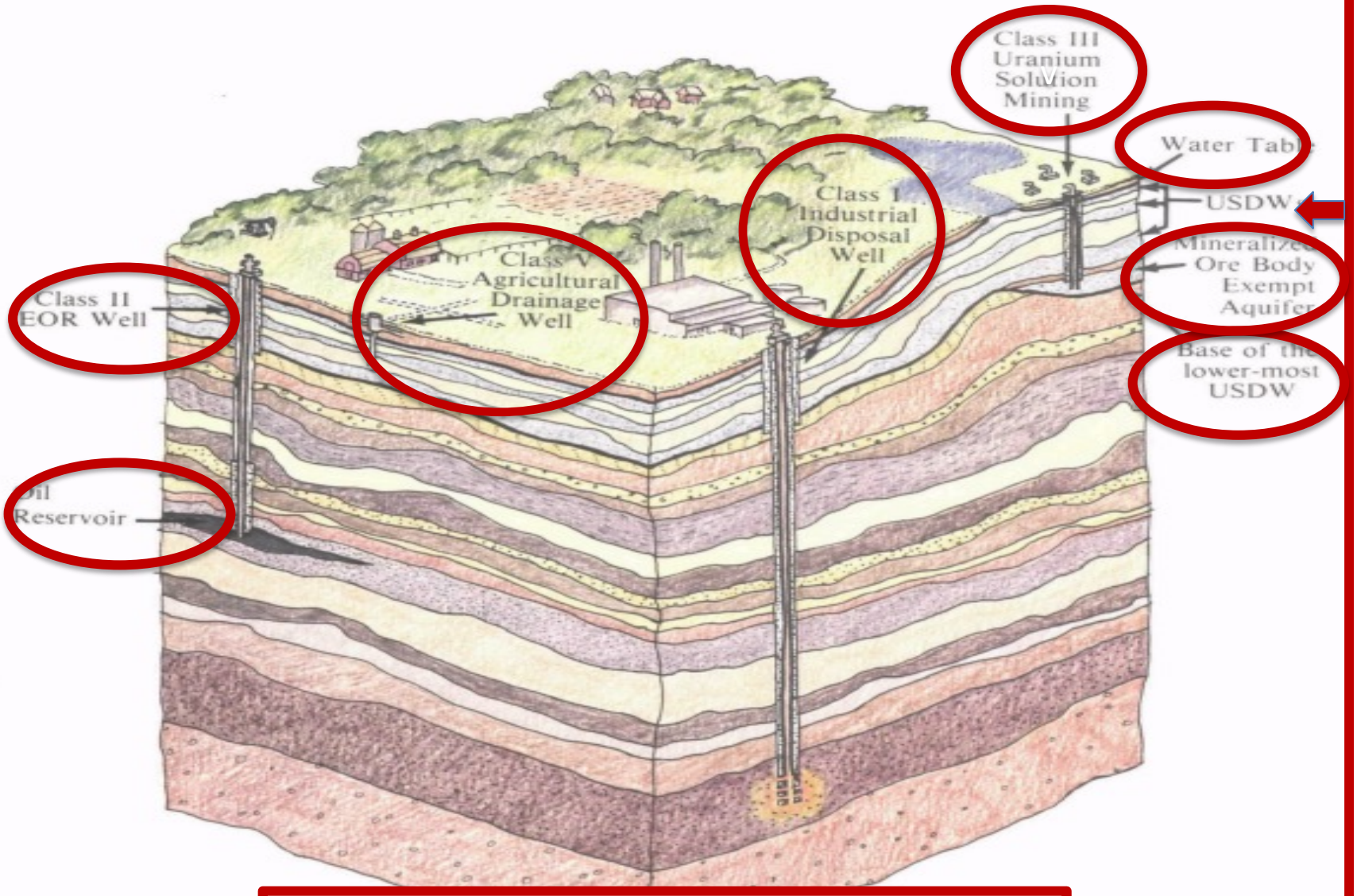
- **DUG WELLS**
  - ✓ Hacking at the ground with a pick and shovel is one way to dig a well.
  - ✓ Disadvantages of this type of well are that they are shallow and lack continuous casing, and they go dry during periods of drought
- **DRIVEN WELLS**
  - ✓ Driven wells are still common today.
  - ✓ They are built by driving a small-diameter pipe into soft earth, such as sand or gravel
  - ✓ They can only tap shallow water, and because the source of the water is so close to the surface, **contamination** from surface pollutants can occur.
- **DRILLED WELLS**
  - ✓ Most modern wells are drilled, which requires a fairly complicated and expensive drill rig.
  - ✓ Drill rigs are often mounted on big trucks.
  - ✓ They use rotary drill bits that chew away at the rock, percussion bits that smash the rock, or, if the ground is soft, large auger bits.
  - ✓ Drilled wells can be drilled more than 1,000 feet deep. Often a pump is placed in the well at some depth to push the water up to the surface.

First Dug Well



Early plumbers

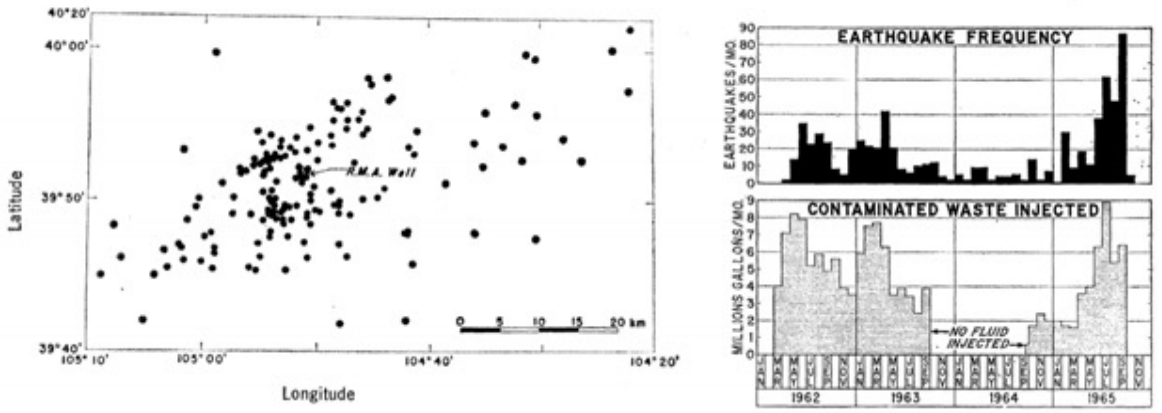
INJECTION WELLS



Different Classes of Injection Wells In-situ

The Underground Injection Control program consists of six classes of injection wells. Each well class is based on the type and depth of the injection activity, and the potential for that injection activity to result in endangerment of a USDW.

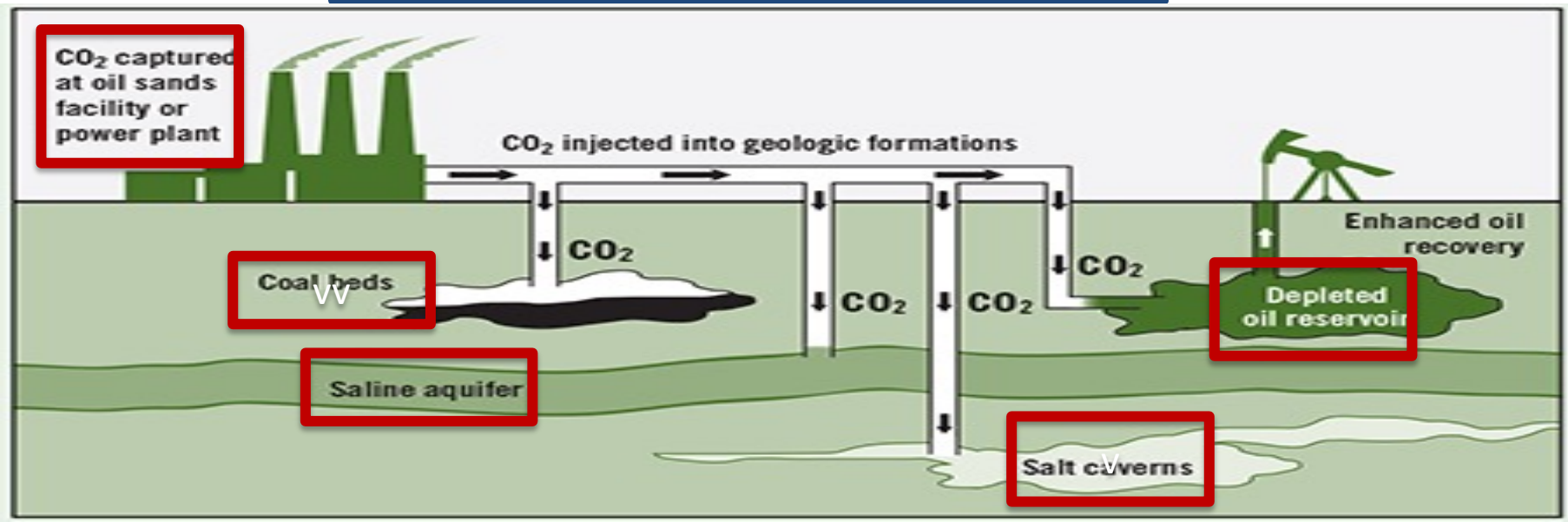
- Class I wells are used to inject hazardous and non-hazardous wastes into deep, isolated rock formations.
- Class II wells are used exclusively to inject fluids associated with oil and natural gas production.
- Class III wells are used to inject fluids to dissolve and extract minerals.
- Class IV wells are shallow wells used to inject hazardous or radioactive wastes into or above a geologic formation that contains a USDW.
- Class V wells are used to inject non-hazardous fluids underground. Most Class V wells are used to dispose of wastes into or above underground sources of drinking water.
- Class VI wells are wells used for injection of carbon dioxide (CO_2) into underground subsurface rock formations for long-term storage, or geologic sequestration.



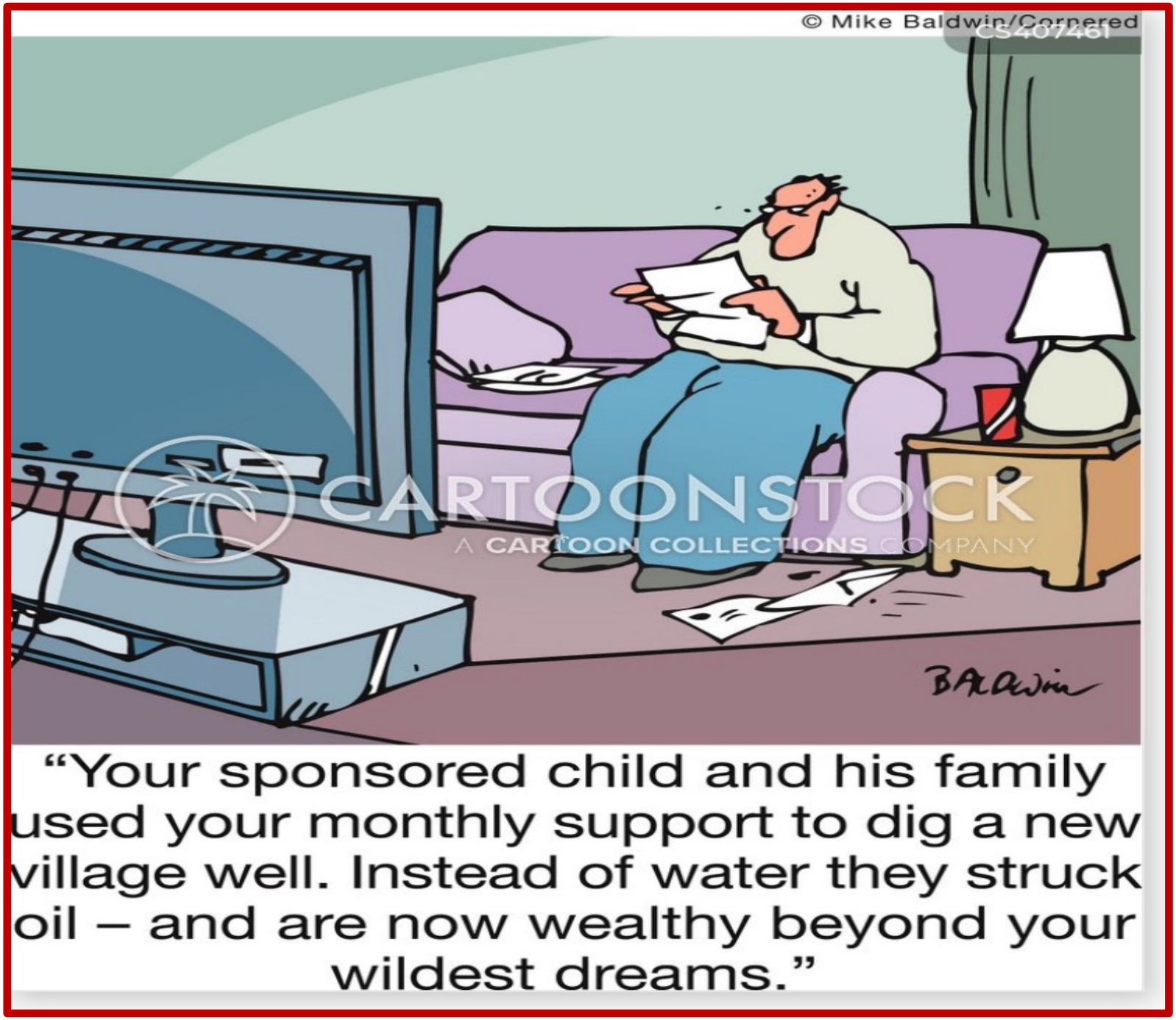
A 1968 publication showing the correlation between fluid injection and earthquakes at the Rocky Mountain Arsenal, Denver, Colorado. (Left) Location of wastewater disposal well and epicenters of earthquakes. (Right) Correlation between the number of earthquakes and the volume of fluid injected.

- The **Rocky Mountain Arsenal** was a United States chemical weapons manufacturing center located in the Denver Metropolitan Area. The site was completed December 1942, operated by the United States Army throughout the later 20th century and was controversial until its closure in 1992
  - ✓ In 1961, the Army constructed a 12,000 foot injection well for the disposal of wastes.
  - ✓ This resulted in subsequent earthquakes in Denver area.
- In 1975, Colorado Department of Public Health and Environment ordered the Army to stop the non-permitted discharge of contaminants, to control the contaminated groundwater leaving the site, and to implement a monitoring plan.
  - ✓ The Army took remedial actions to prevent the contamination that includes the installation of the groundwater barrier system which treated approximately 1 billion gallons of water every year.
  - ✓ The deep injection well was closed in 1985

CARBON CAPTURE AND STORAGE



- **CO2** storage is a little more complicated than simply locking the captured gas into a vessel and throwing away the key.
- Carbon storage involves **transporting the captured CO2**, usually in liquid form via pipeline, and injecting it deep underground in geologic formations.
- The U.S. Department of Energy is investigating five types of underground formations for geologic carbon storage:
  1. **Saline formations**
  2. **Oil and natural gas reservoirs**
  3. **Unmineable coal seams**
  4. **Organic-rich shales**
  5. **Basalt formations**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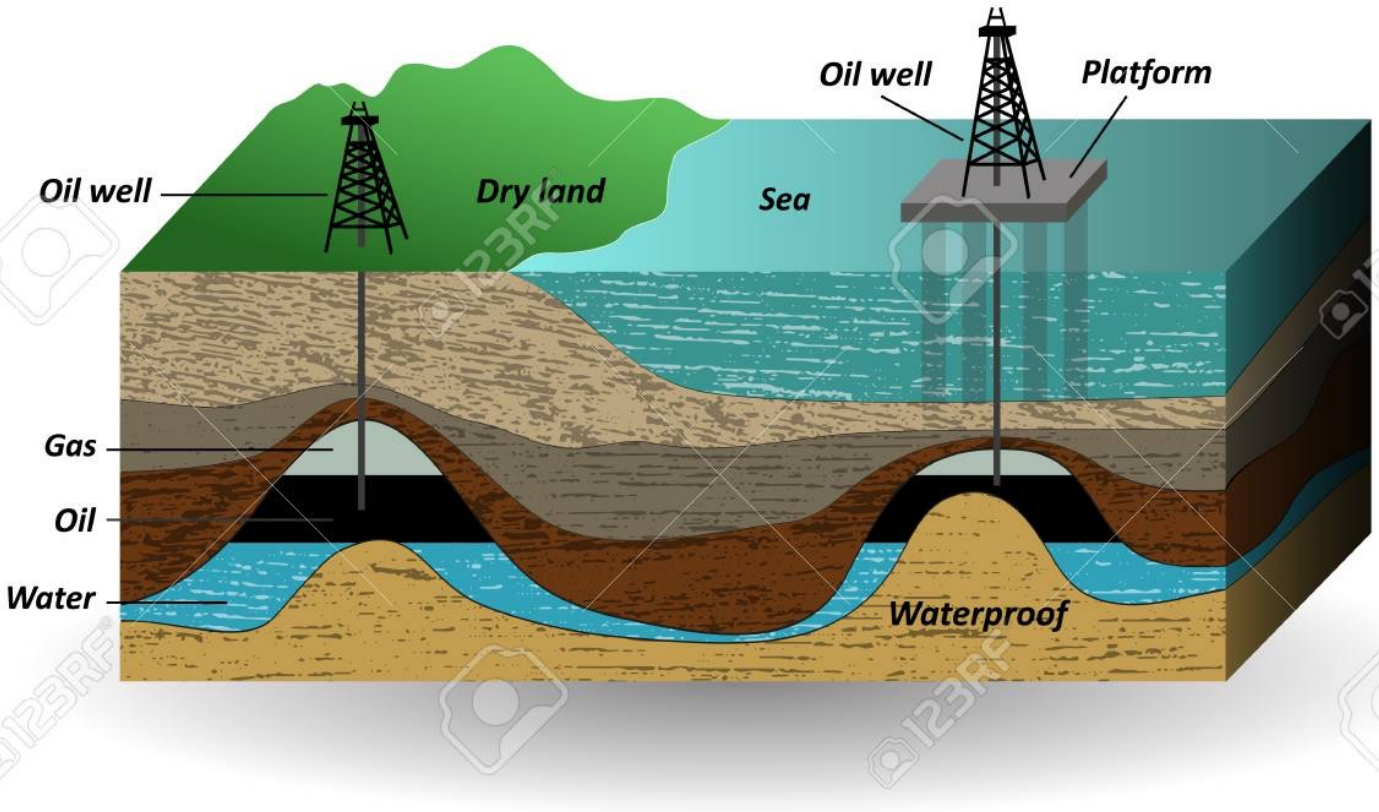
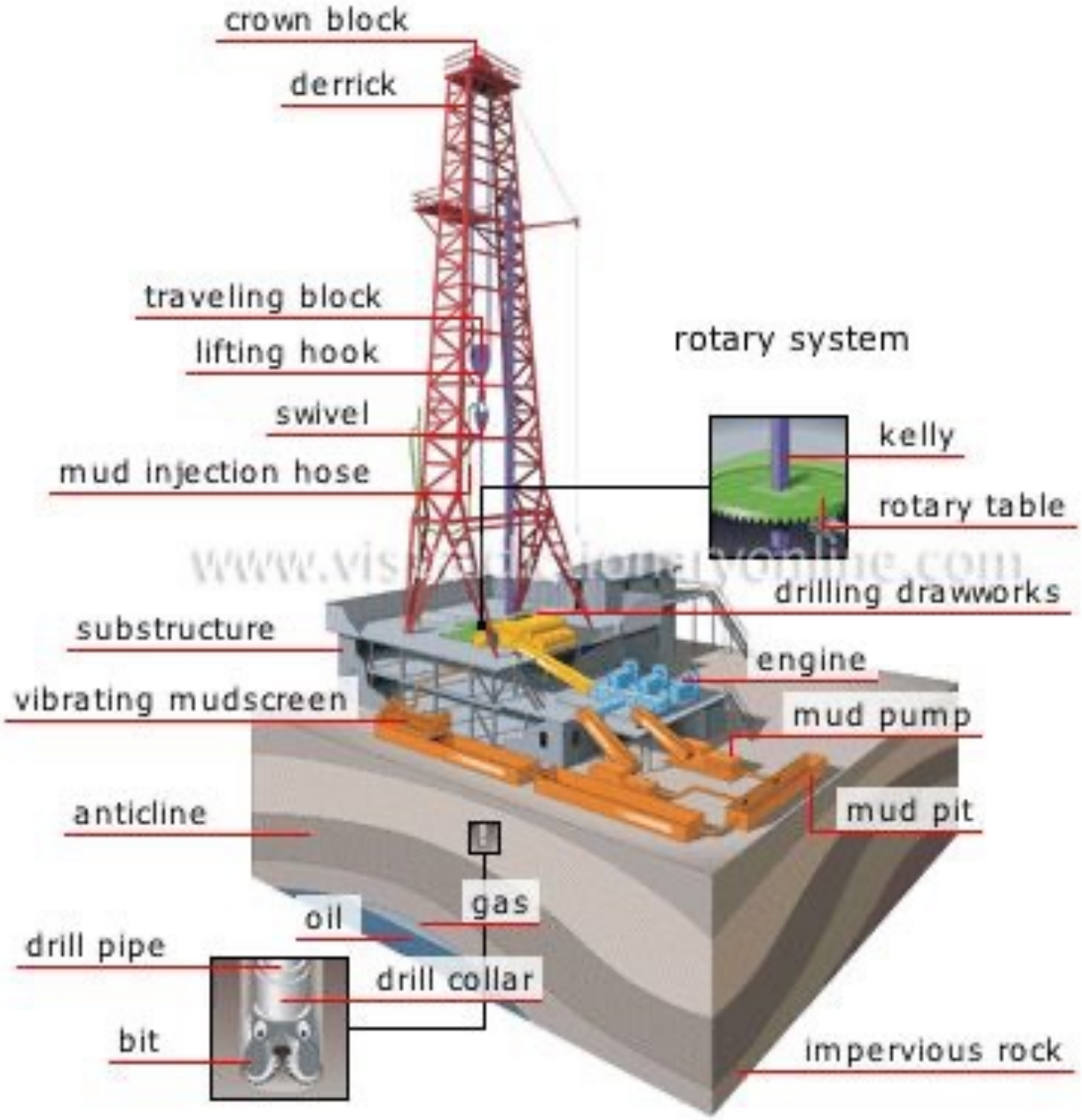
BALdwin
"Your sponsored child and his family used your monthly support to dig a new village well. Instead of water they struck oil – and are now wealthy beyond your wildest dreams."

EXTRACTION WELLS

OIL WELL STRUCTURE

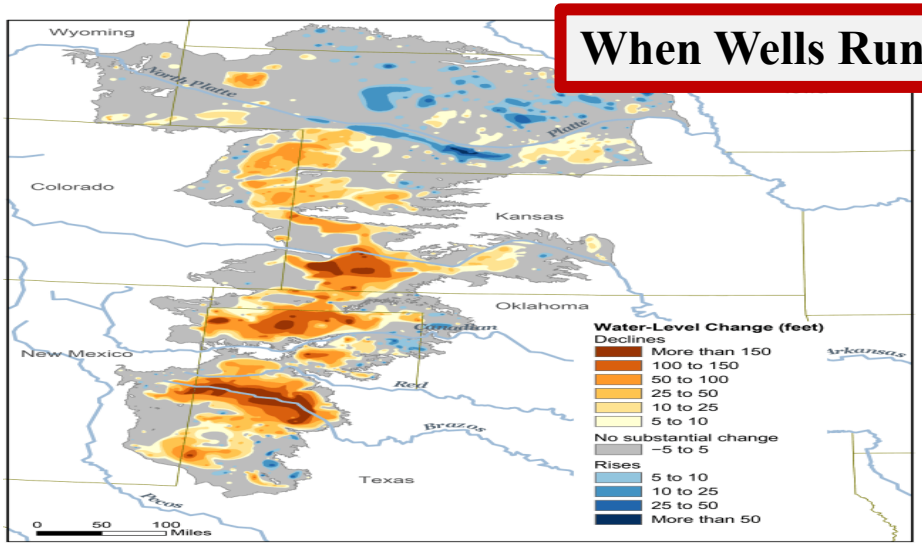


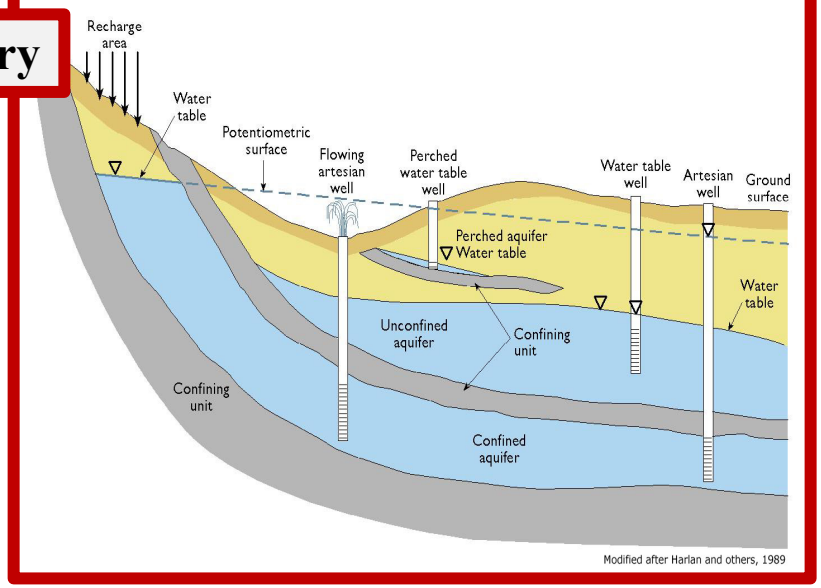

crown block
derrick
traveling block
lifting hook
swivel
mud injection hose
rotary system
kelly
rotary table
drilling drawworks
substructure
engine
vibrating mudscreen
mud pump
anticline
mud pit
gas
oil
drill pipe
drill collar
bit
impervious rock

- Many people in the United States receive their water from private ground water wells.
- EPA regulations that protect public drinking water systems do not apply to privately owned wells.
- As a result, owners of private wells are responsible for ensuring that their water is safe from contaminants.
- Health risks include
  - ✓ **diarrhea**
  - ✓ **vomiting**
  - ✓ **cramps**
  - ✓ **nausea**
  - ✓ **headaches**
  - ✓ **fever**
  - ✓ **fatigue**
  - ✓ and even death sometimes
- Infants, children, elderly people, and people with weakened immune systems are more likely to get sick or die from disease-causing microorganisms in drinking water

A schematic of how a typical single-home domestic water well works.

When Wells Run Dry





Is the Ogallala Aquifer in danger? Today the Ogallala Aquifer is being depleted at an annual volume equivalent to 18 Colorado Rivers.

What has put the Ogallala Aquifer at risk? Widespread irrigation for farming accounts for 94% of groundwater use. Recent western droughts are also responsible.

How many years until the Aquifer runs out? Within 50 years, the entire aquifer is expected be 70% depleted

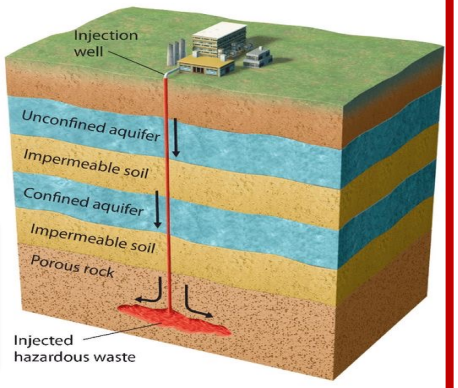
How long before the Great Plains run out of water? The aquifer would be seventy percent depleted by 2060

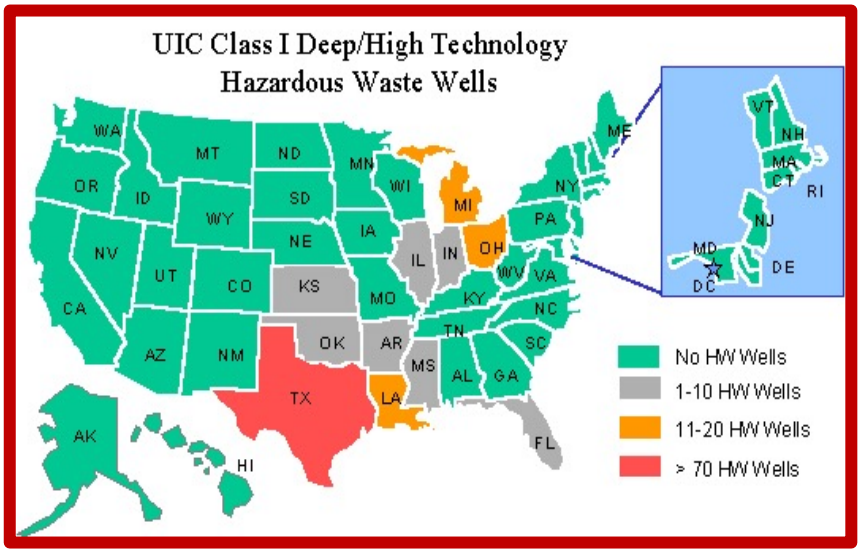
Can the Ogallala Aquifer be saved? The Aquifer could be exhausted within this century take 6,000 years to restore.

Lesson 19.3 Hazardous Waste

Hazardous Waste Disposal

- **Landfills:** Specifically designed to keep hazardous waste contained
- **Surface impoundment:** Liquid waste poured into shallow lined pits; water evaporates and solid waste is transported elsewhere
- **Deep-well injection *(see diagram on right):*** Wastes injected into deep, confined porous rock layers
- Deep-well injection video

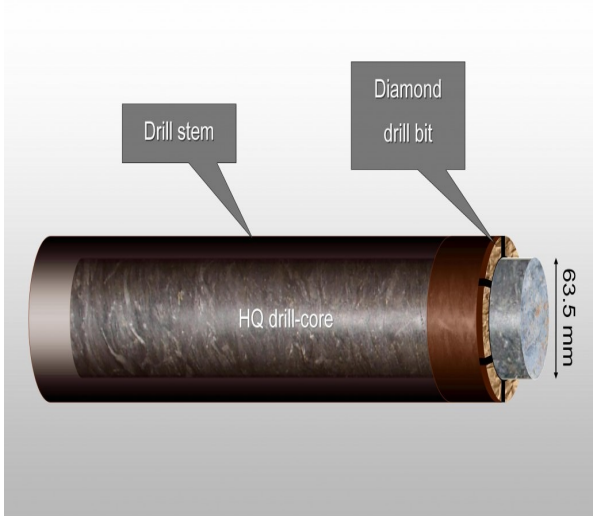




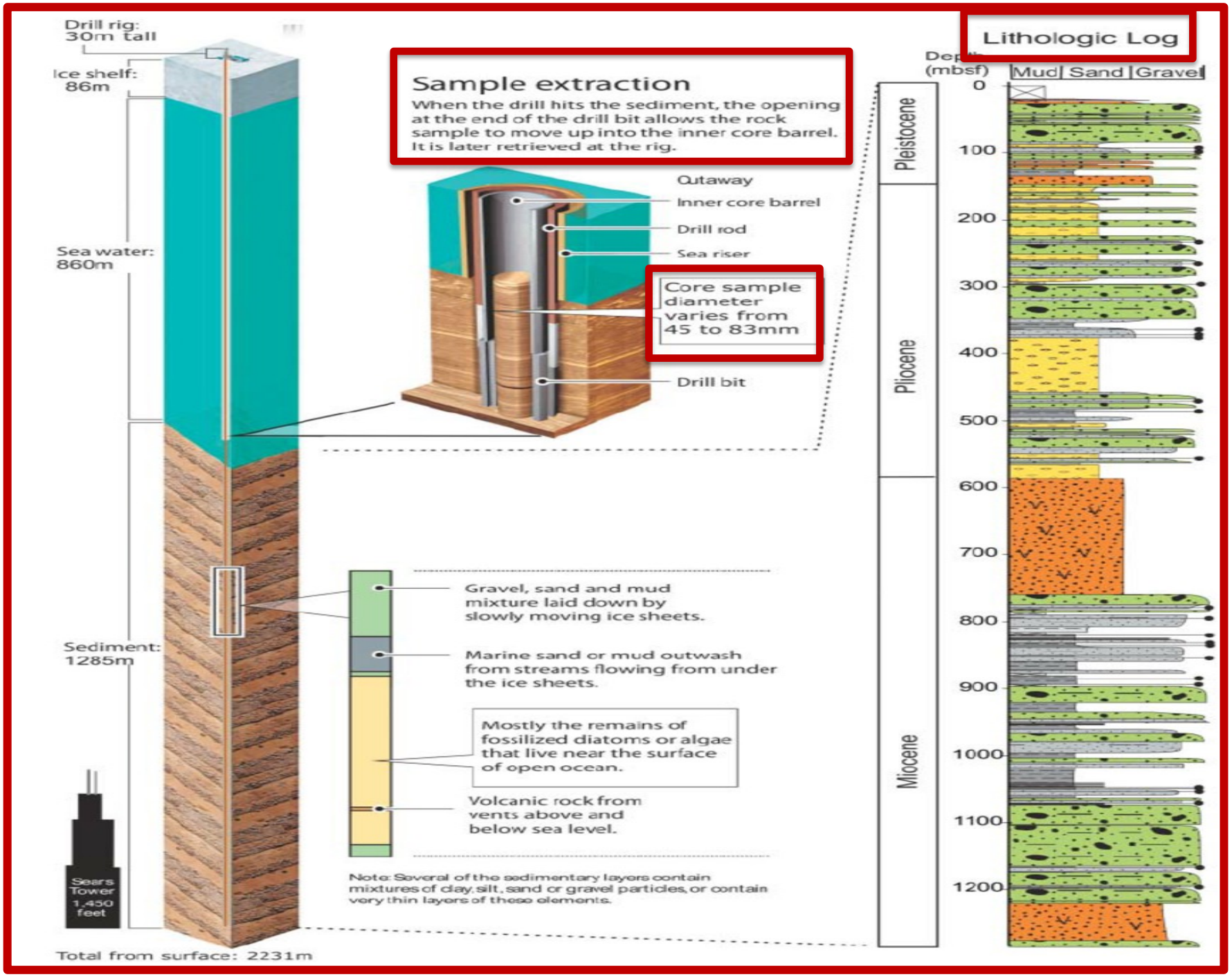
- There are more than 680,000 underground waste and injection wells nationwide, more than 150,000 of which shoot industrial fluids thousands of feet below the surface.
  - ✓ Scientists and federal regulators acknowledge they do not know how many of the sites are leaking.
- Waste simply seeps out, filling tiny spaces left between the grains in the rock like the gaps between stacked marbles.
- Many scientists and regulators say the alternatives to the injection process — burning waste, treating wastewater, recycling, or disposing of waste on the surface — are far more expensive or bring additional environmental risks.

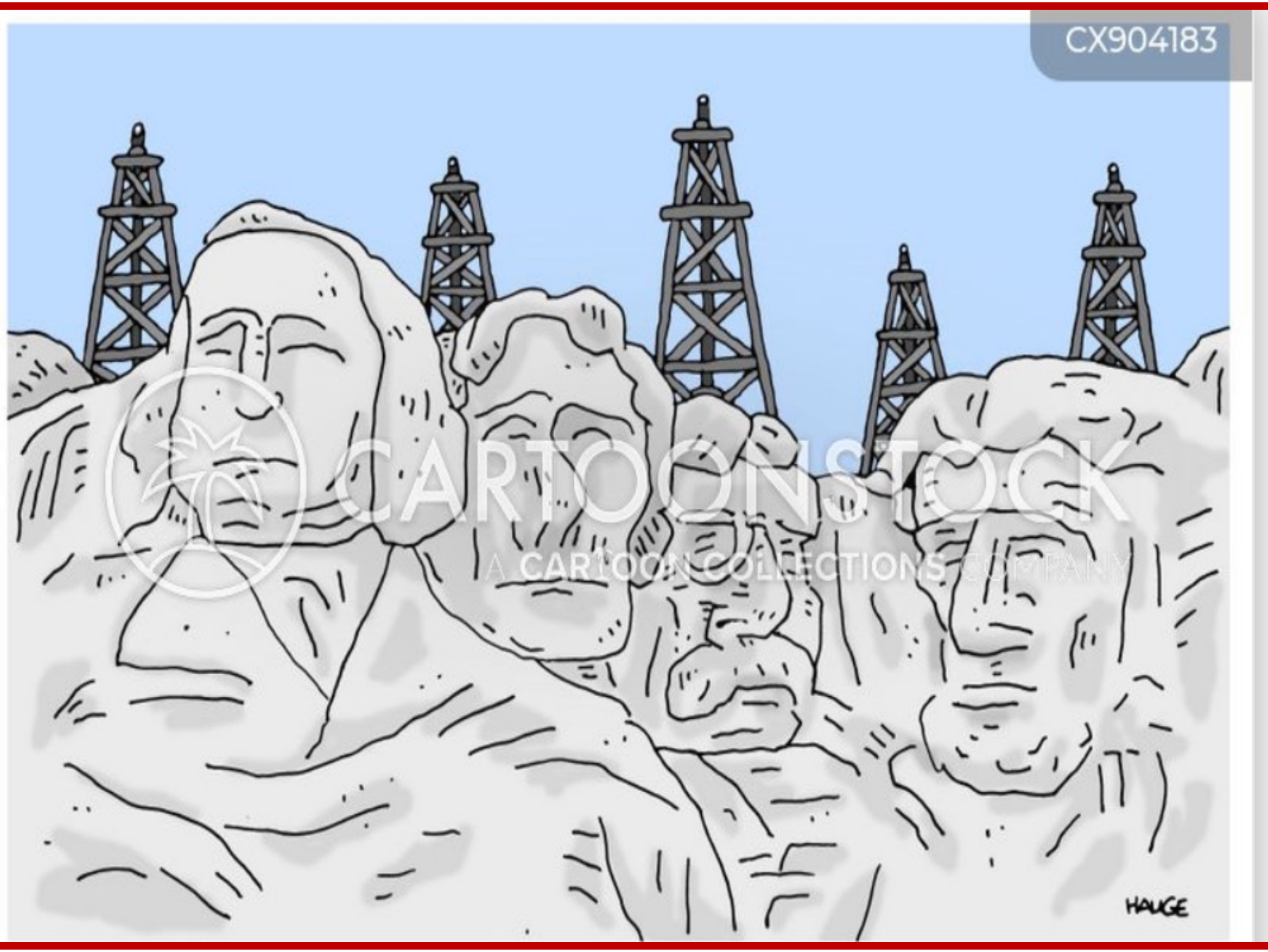
"Well number 34 has run dry
and is now pumping fossils."

CORE DRILLING IN ROCK



- The primary purpose of a core drilling is **to obtain an undisturbed, intact sample representative of the in situ material**.
- A diamond bit attached to a core barrel is lowered into the hole on the end of drill rods.
- Rock core samples are obtained by removing the inner barrel assembly from the core barrel of the drill rod.
- Rock cuttings are removed from the bore hole.
- Drill holes are generally 1,000 to 5,000 feet deep.
- On average, a 2,000-foot hole takes **six to 10 days** to drill.
- Core of about 2 to 3.5 inches in diameter is typically drilled.


Drill rig:
30m tall
Ice shelf:
86m
Sea water:
860m
Sediment:
1285m
Sears Tower
1,450 feet
Total from surface: 2231m
Sample extraction
When the drill hits the sediment, the opening at the end of the drill bit allows the rock sample to move up into the inner core barrel. It is later retrieved at the rig.
Cutaway
Inner core barrel
Drill rod
Sea riser
Core sample diameter varies from 45 to 83mm
Drill bit
Gravel, sand and mud mixture laid down by slowly moving ice sheets.
Marine sand or mud outwash from streams flowing from under the ice sheets.
Mostly the remains of fossilized diatoms or algae that live near the surface of open ocean.
Volcanic rock from vents above and below sea level.
Note: Several of the sedimentary layers contain mixtures of clay, silt, sand or gravel particles, or contain very thin layers of these elements.
Lithologic Log
Depth (mbsf)
Mud
Sand
Gravel
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Pleistocene
Pliocene
Miocene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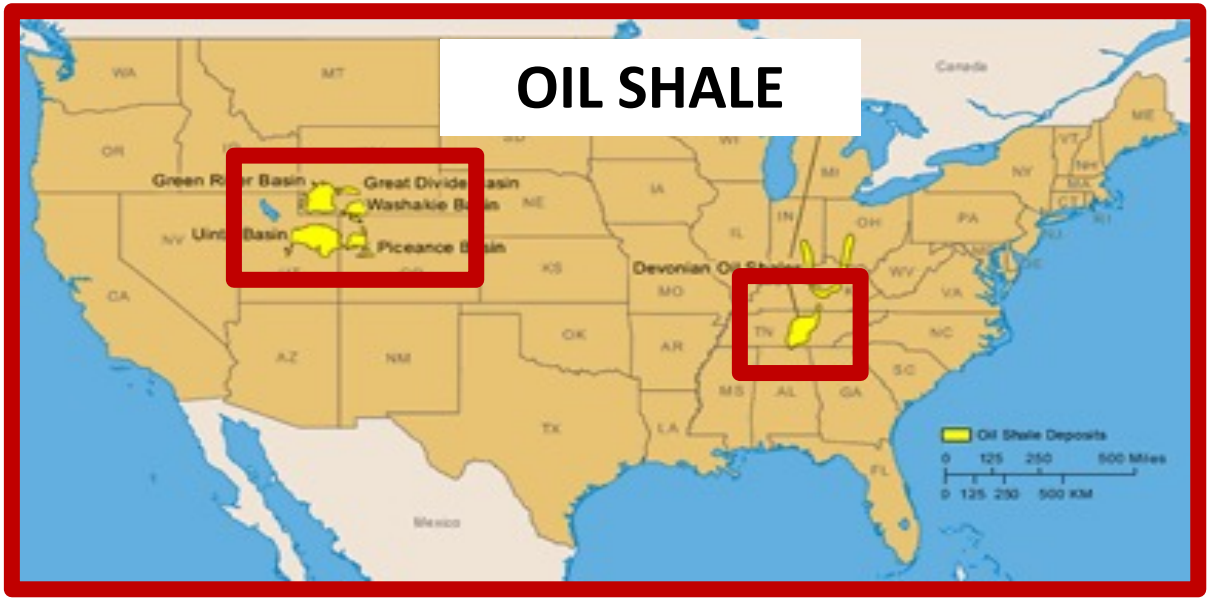
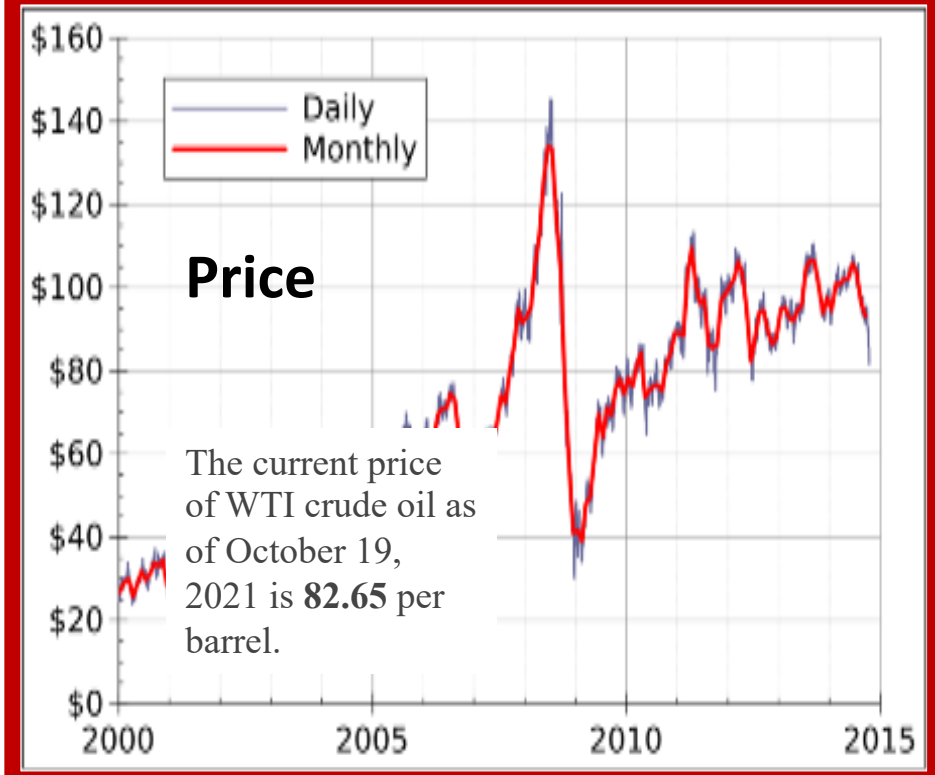
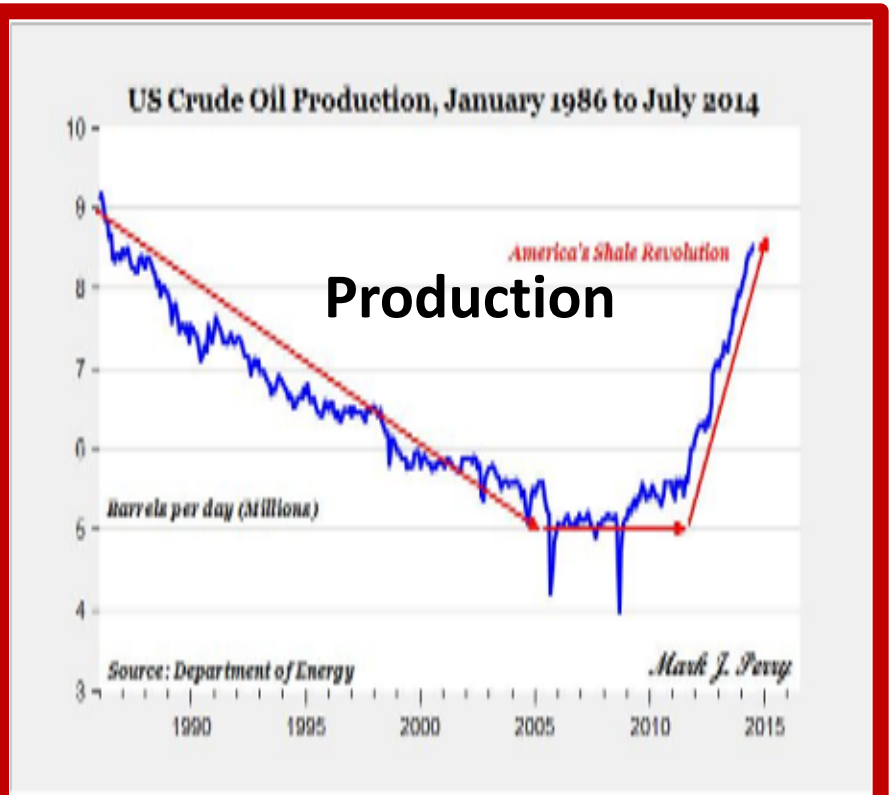
FRACKING

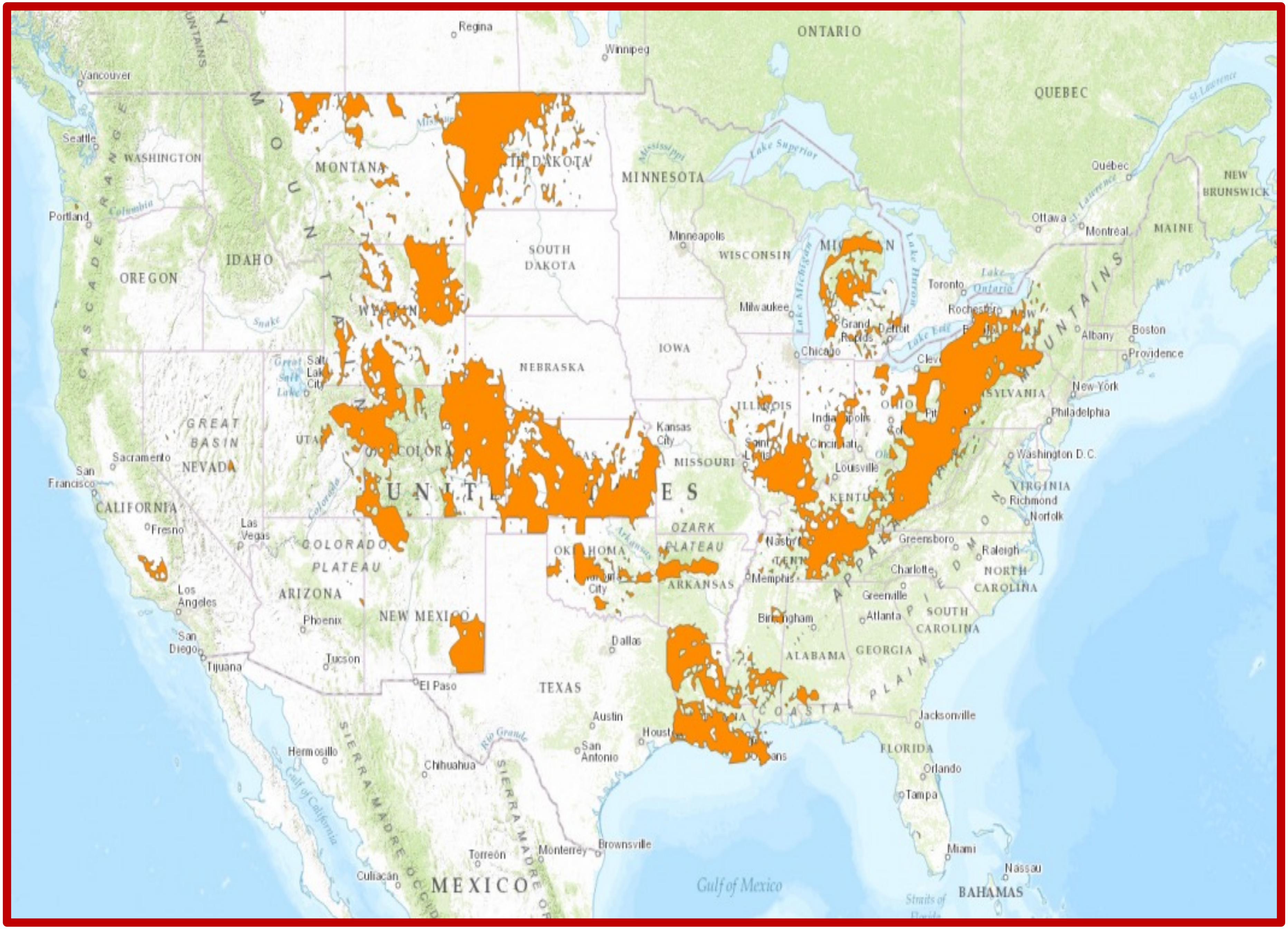


- *Oil shale* is different than *shale oi*l in that oil shale is essentially rock that contains a compound called kerogen, which is used to make oil.
- Two methods have been developed to extract petroleum products from oil shale.
  - ✓ Mine it like the rock it is, and t heat it in the low-oxygen environment needed to turn the kerogen into oil and gas.
  - ✓ Heat the oil in situ, applying heat to the formation, and then pumping out the resulting oil.
- Shale oil refers to hydrocarbons that are trapped in formations of shale rock.
- Fracking is a process that oil companies use to drill down into the layers of shale and open up the rock formations so that oil can be extracted.

- Modern day fracking didn't begin until the 1990s when a new technique was created which took hydraulic fracturing and combined it with horizontal drilling.
- Hydraulic fracturing has been around for 100+ years.
- Why did this shale oil production boom occur so long after the technology was created?
- These two charts will help explain why.



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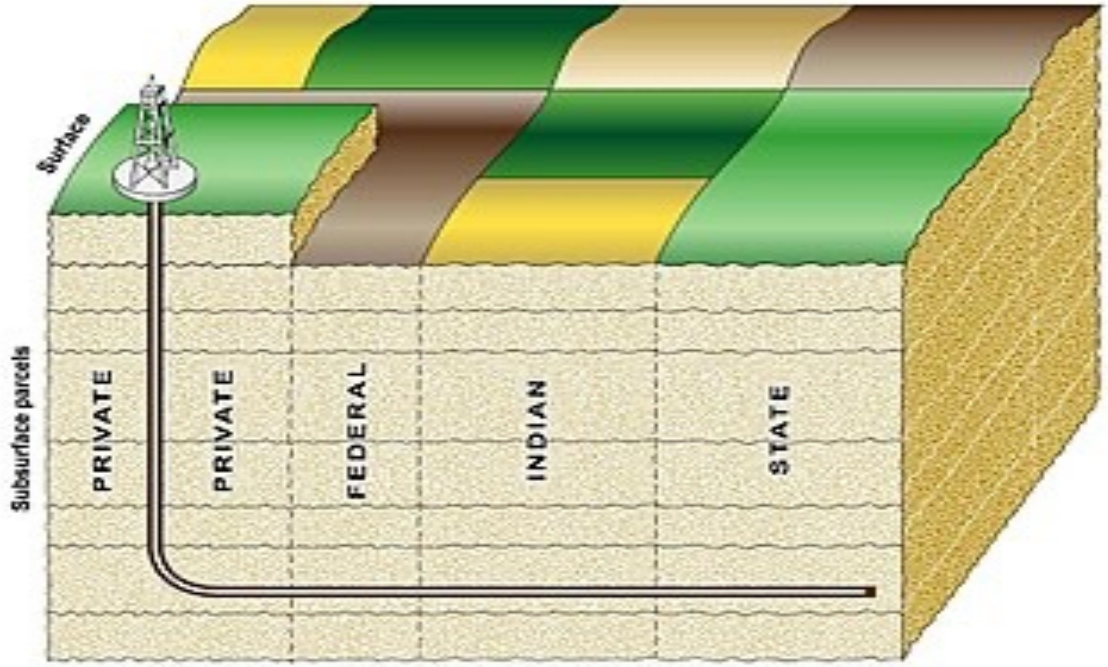
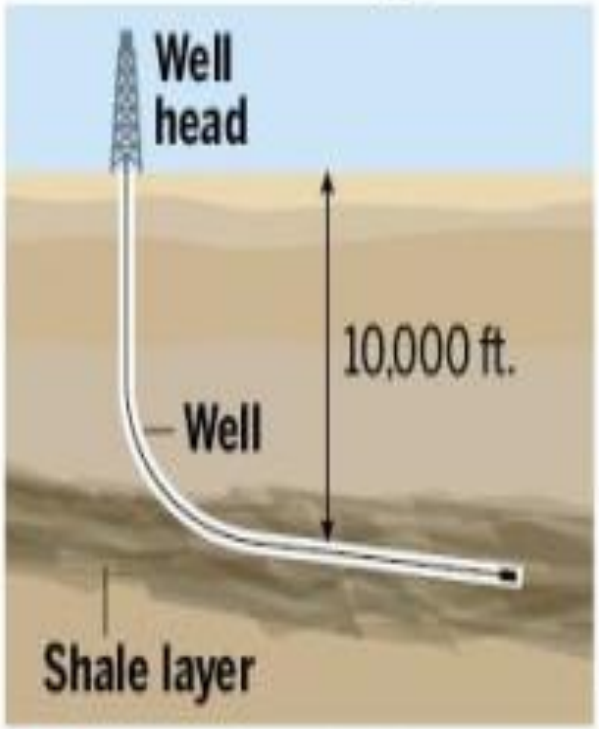
SOUTH
CAROLINA
ALABAMA
GEORGIA
Jacksonville
FLORIDA
Orlando
Tampa
Miami
Nassau
BAHAMAS
Gulf of Mexico
Hermosillo
Chihuahua
Torreon
Monterrey
Brownsville
Culiacán
MEXICO
Lake Superior
Lake Michigan
Lake Huron
Lake Ontario
Lake Erie

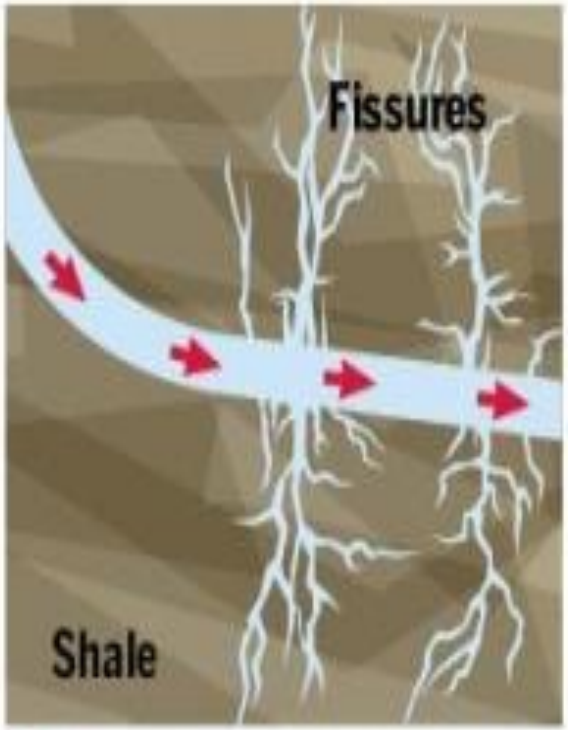
- **Horizontal drilling** is a commonly used technology because drilling at an angle other than vertically can stimulate reservoirs and obtain information that cannot be done by drilling vertically.
- Horizontal drilling can **increase the contact between the reservoir and the wellbore**.

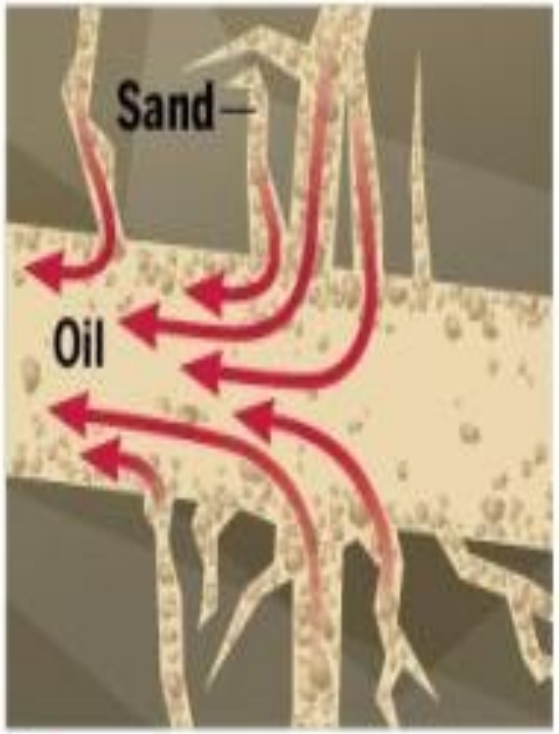


Government Accountability Office depiction of horizontal drilling being used to cross tracts of land with differing owners

How fracking works







1. Wells are bored using directional drilling, a method that allows drilling in vertical and horizontal directions to depths of over 10,000 feet.

2. Large amounts of water, sand and chemicals are injected into the well at high pressure, causing fissures in the shale.

3. Sand flows into the fissures, keeping them open so that the oil from the shale can flow up and out of the well.

Sources: USC, Los AngelesTimes

McCLATCHY-TRIBUNE

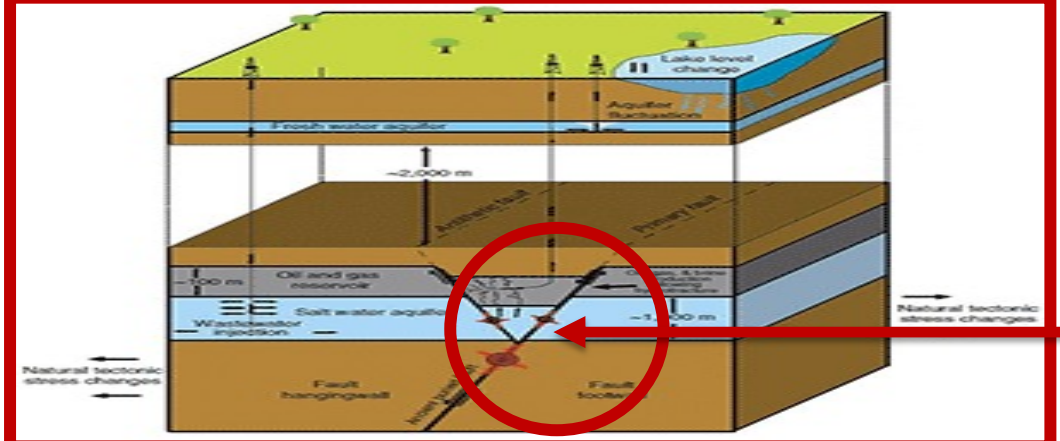
Fracking and Drinking Water

- Fracking can contaminate water supplies if it is not done properly, because the fracking fluid injected into rock to enable gas to be released often contains chemicals.
- Stanford University Scientists find no evidence that fracking chemicals seeped into drinking water.
  - U.S. Department of Energy Current findings are:
    - ✓ 1) no evidence of gas migration from the Marcellus Shale; and
    - ✓ 2) no evidence of brine migration from the Marcellus Shale."

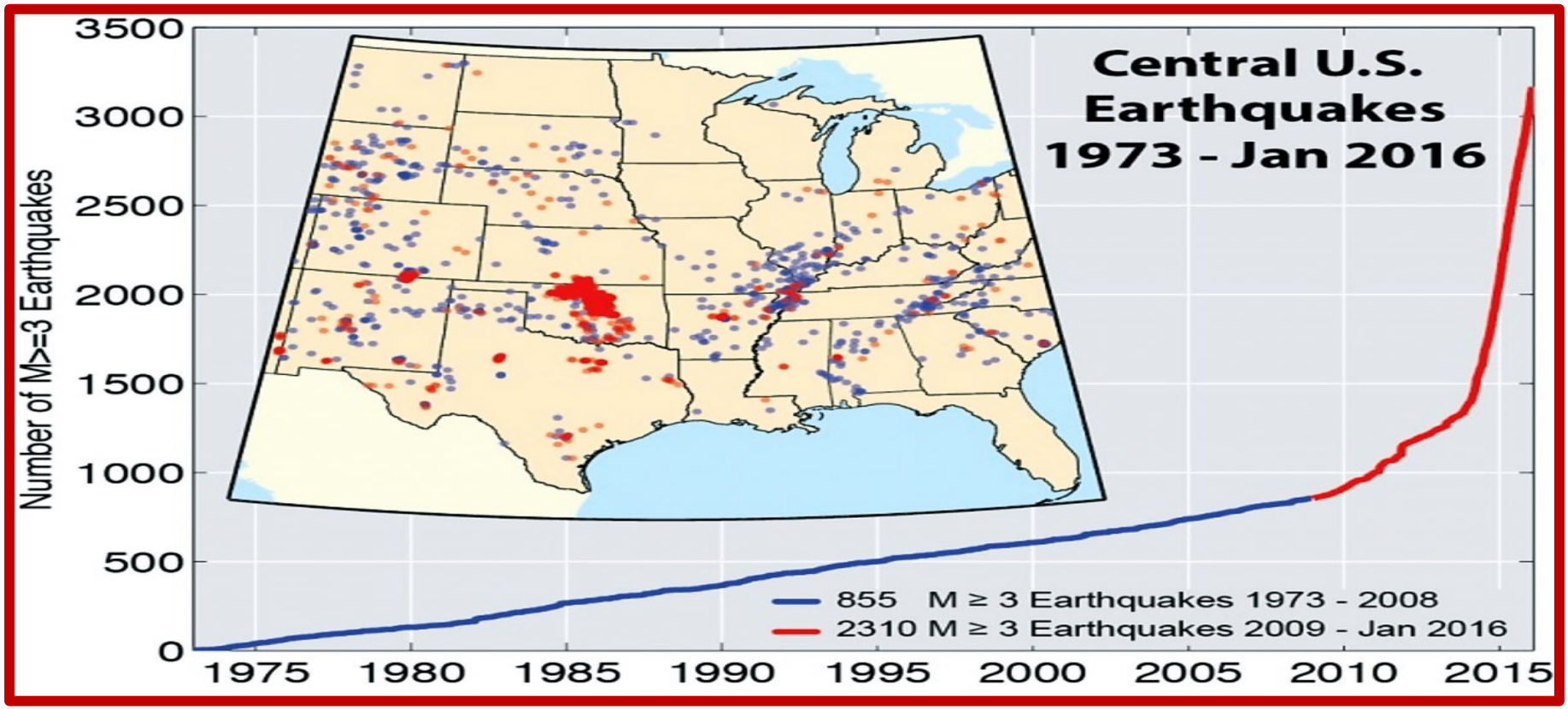
Fracking does not cause burning tap water.

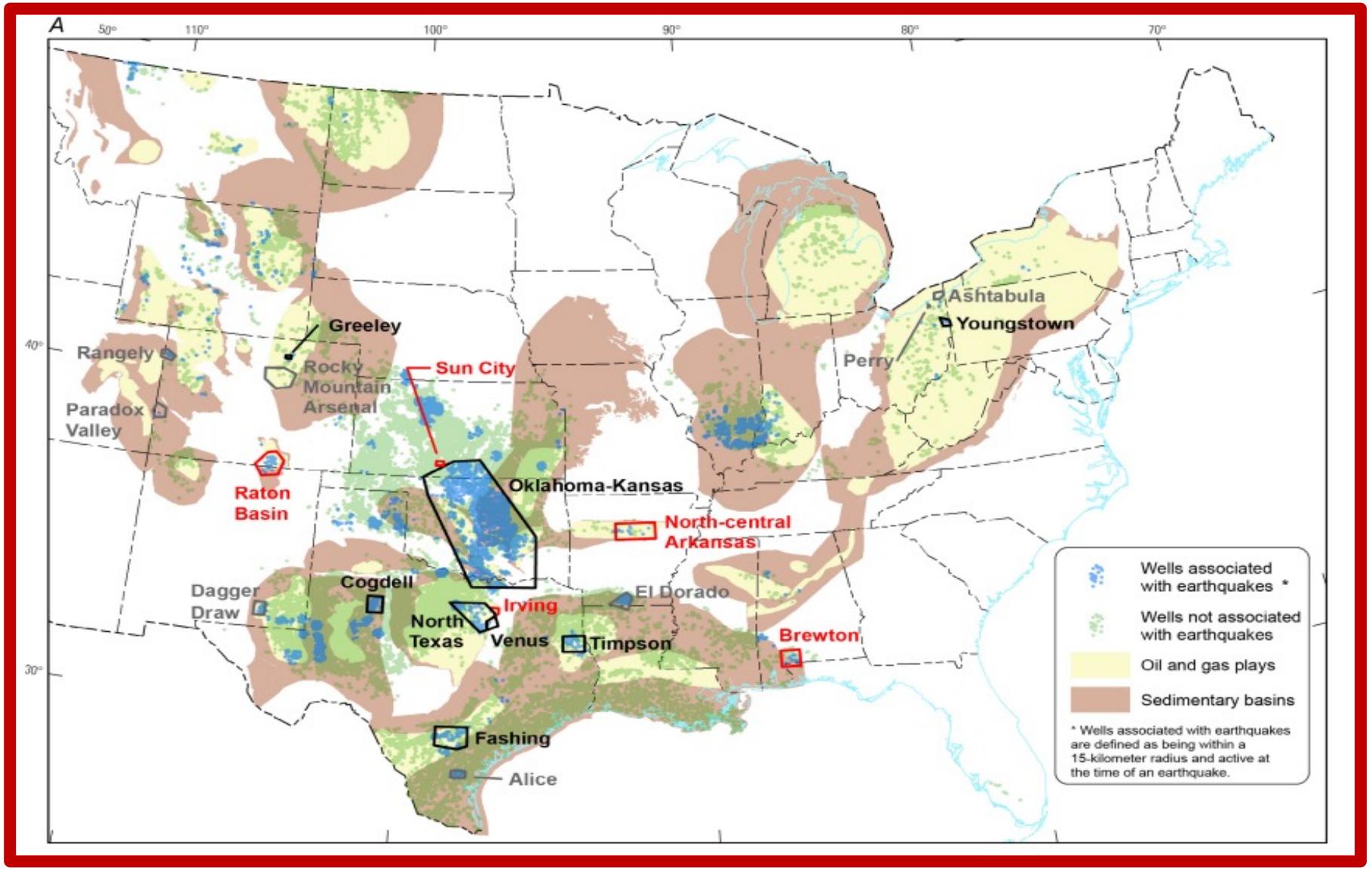
- **Unfortunately, this is difficult to extinguish, so to speak.**
- **The fact is that the State of Colorado investigated these scenes from *GASLAND* and found no connection between oil and natural gas drilling – including fracking or hydraulic fracturing – and reports of tap water catching on fire.**

FRACKING AND EARTH QUAKES



Texas scientists found that injecting waste water into an aquifer at a depth > 7000 feet reactivated ancient faults (thick black lines) and caused earthquakes

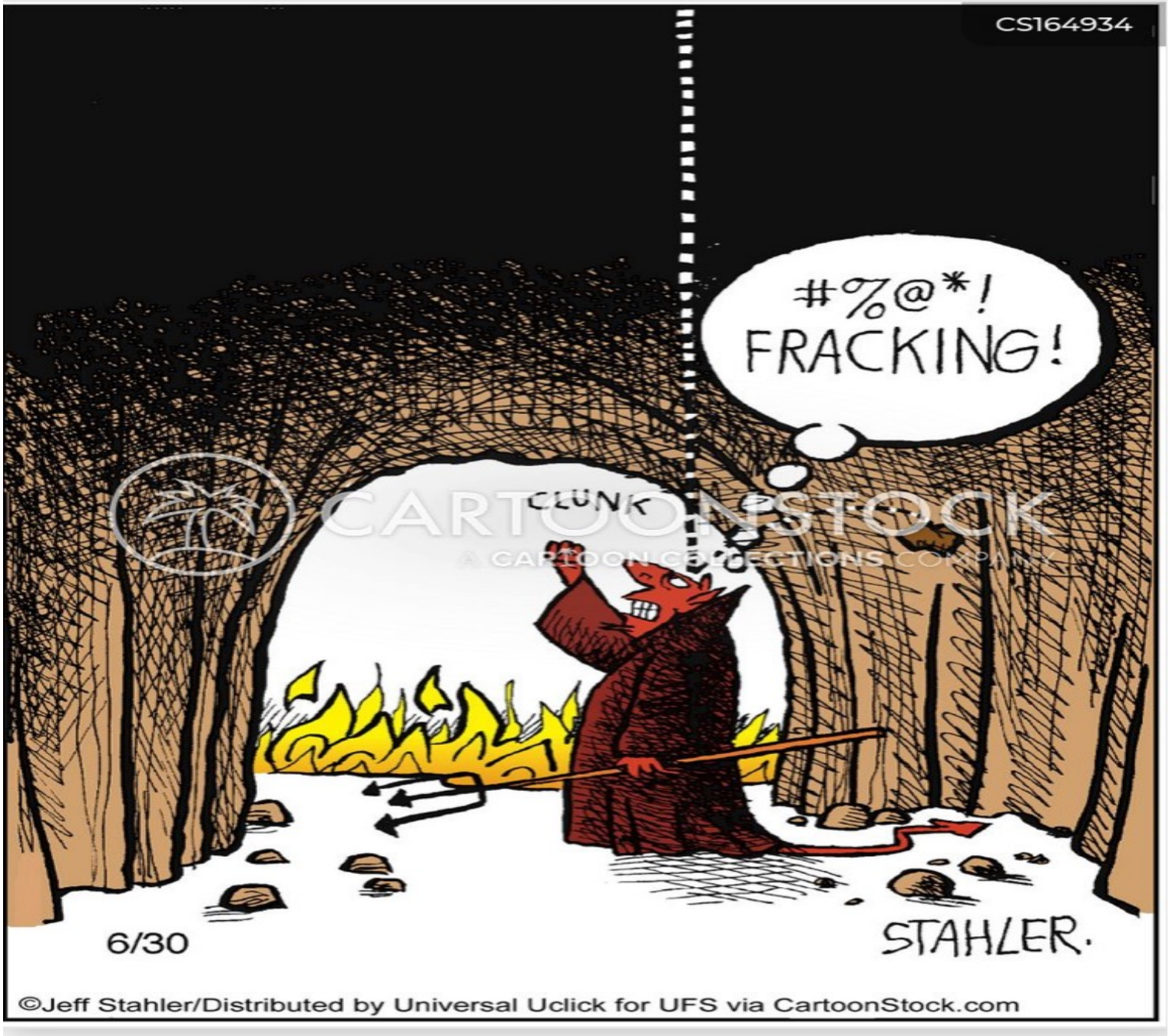




Tight association between Oklahoma natural gas wells and induced seismicity.

FRACKING: PRO VS CON

- PRO FRACKING:
  - ✓ ***Increasing reliance on natural gas, rather than coal as the burning of natural gas produces fewer harmful particles in the air.***
  - ✓ ***The major new supply of natural gas produced through fracking is displacing the burning of coal, which each year contributes to the early death of thousands of people.***
  - ✓ ***Coal made up about 50 percent of U.S. electricity generation in 2008, 37 percent by 2012; meanwhile, natural gas went from about 20 percent to about 30 percent during that same period.***
  - ✓ ***In particular, nitrogen oxide and sulfur dioxide emissions have been reduced.***
- ***CON FRACKING:***
  - ✓ ***First, it is not the case that a new natural gas facility coming online always replaces a legacy coal-fired power plant.***
  - ✓ ***Second, air quality dynamics around fracking operations are not fully understood, and cumulative health impacts of fracking for nearby residents and workers remain largely unknown.***
  - ✓ ***Some of the available research evidence from Utah and Colorado suggests there may be under-appreciated problems with air quality, particularly relating to ozone.***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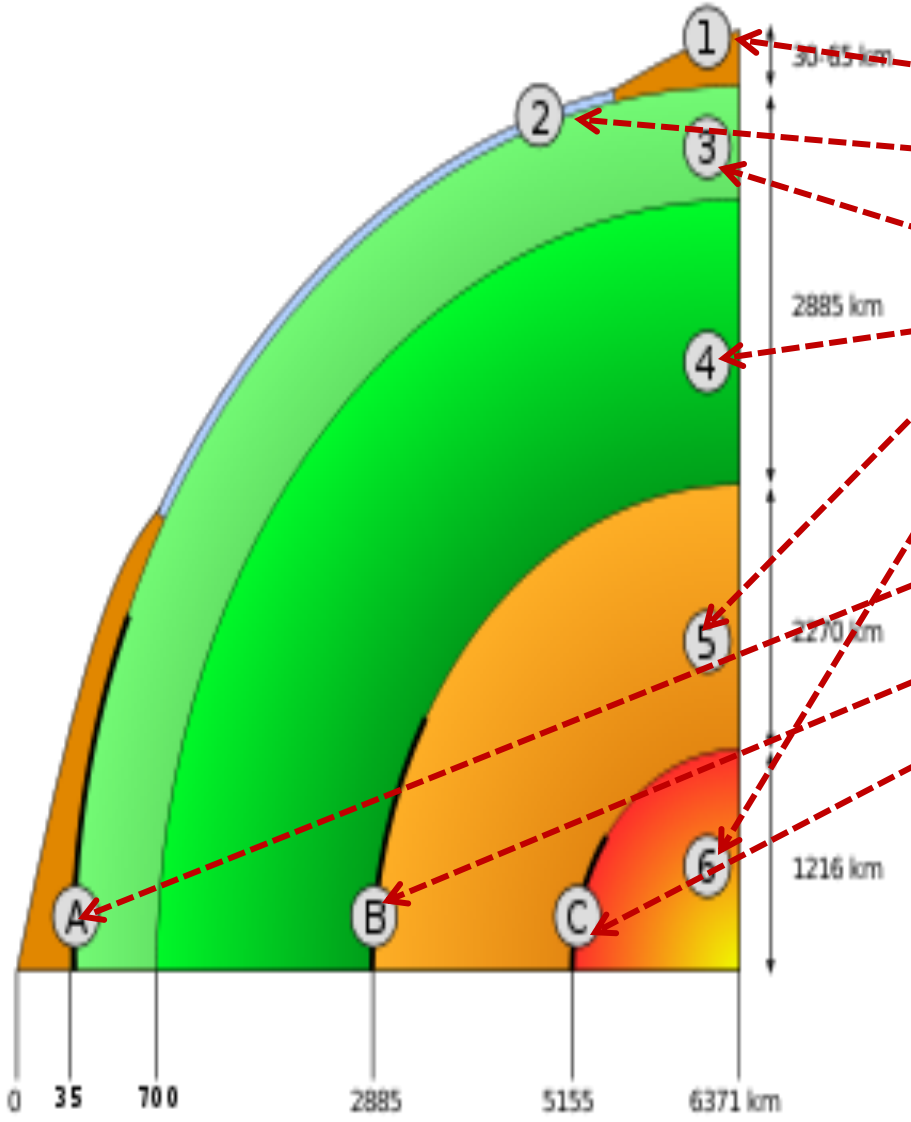
THE EARTH'S INTERIOR: WHAT'S OUR BEST GUESS?

Deepest Wells

- **Project Mohole** was an attempt in the early 1960s to drill through the Earth's crust to obtain samples of the Mohorovičić discontinuity, or Moho, the boundary between the Earth's crust and mantle.
  - ✓ While such a project was not feasible on land, drilling in the open ocean was more feasible, because the mantle lies much closer to the sea floor.
  - ✓ The project suffered from political and scientific opposition, mismanagement, and cost overruns. The U.S. House of Representatives defunded it in 1966.
- Then What is the deepest well?
  - ✓ **Kola Superdeep Borehole** (*Door to Hell*)
  - ✓ In 1970, Soviet geologists set their drills over the Kola Peninsula, which juts eastward out of the Scandinavian landmass.
  - ✓ The borehole was kept open until **2005**.
  - ✓ The deepest part of the hole, reached 12,261 meters or **7.6 miles below the s**urface in 1989.

Earth's Interior as Inferred Today Part -- I

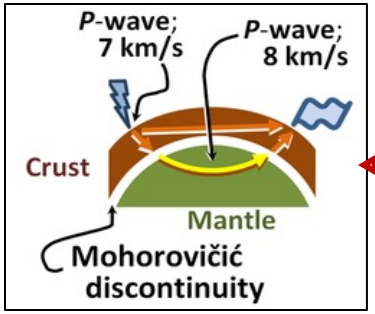


1. Continental crust
2. Oceanic crust
3. Upper mantle
4. Lower mantle
5. Outer core
6. Inner core

A: Mohorovičić discontinuity

B: Gutenberg Discontinuity

C: Lehmann discontinuity

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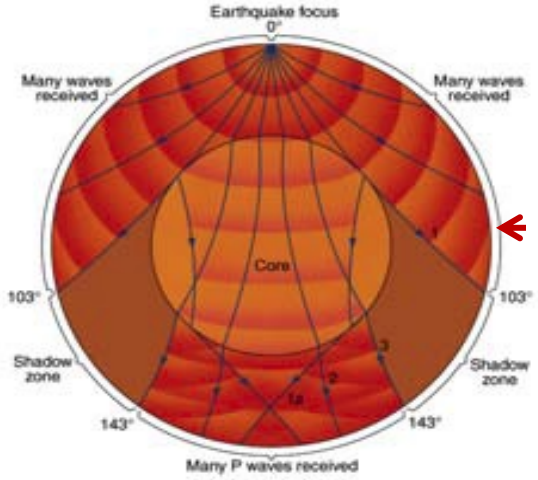
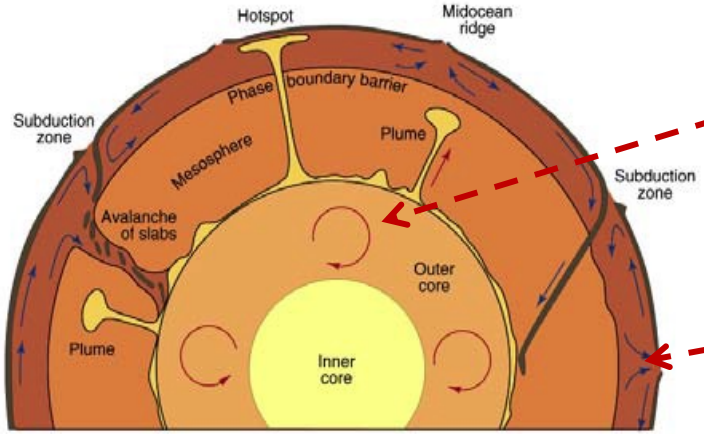
WELL, WITH THE OIL MARKET DOWN, WE MIGHT DO BETTER DRILLING FOR HAND SANITIZER.

WHAT ARE OUR BEST GUESSING TOOLS?

Earthquakes and the Earth's Interior



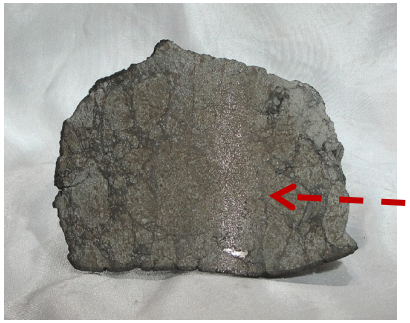
- Processing readings from many seismometers using seismic tomography, seismologists have mapped the mantle of the earth to a resolution of several hundred kilometers.



- Convection in the Earth
  - ✓ In the core
    - ➢ Seismic waves show composition & structure of core
    - ➢ 3-D models show flowing molten Iron
  - ✓ In the mantle
    - ➢ complex convection system

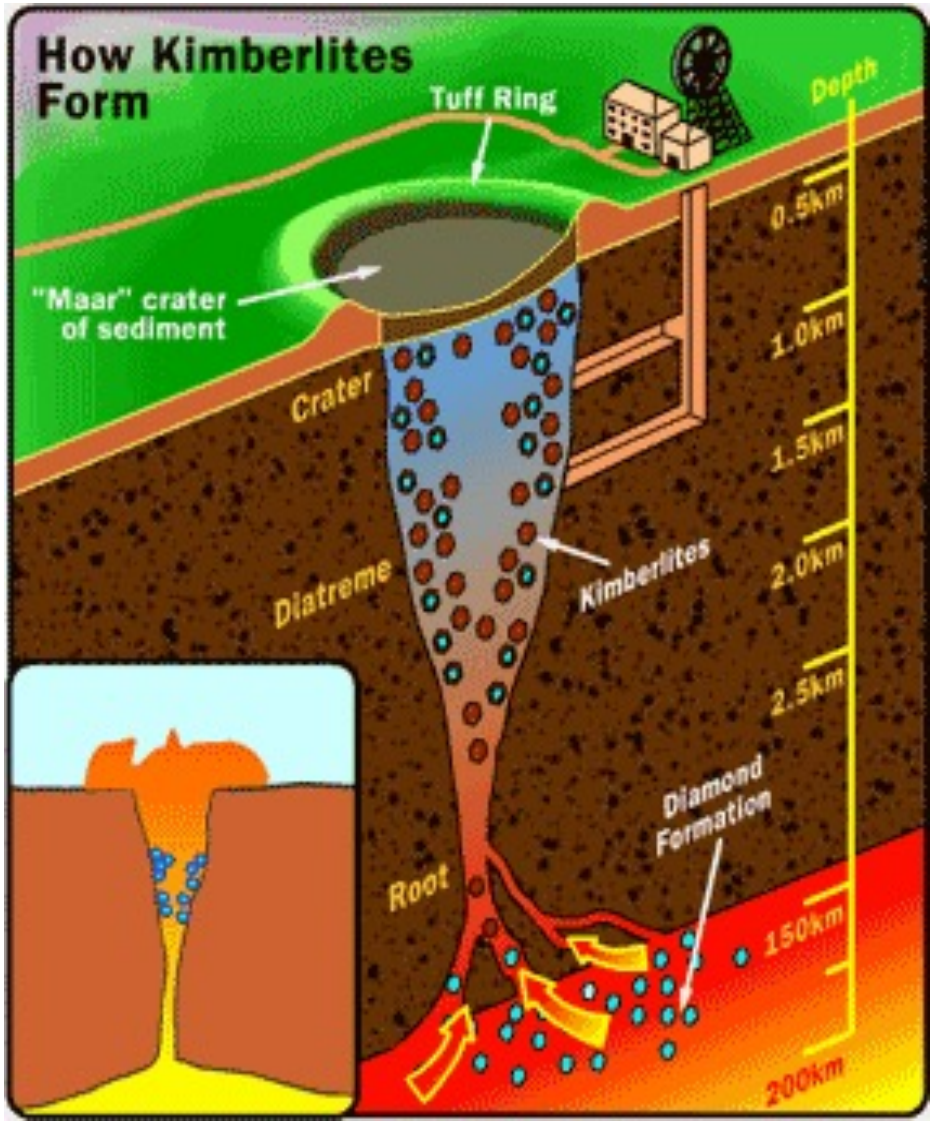
Meteorites and the Earth's Interior

The composition of meteorites is the major line of evidence for "guessing" at the composition of the inner and outer core.



- **There are several kinds of meteorites, and they can tell us different things.**
  - **Chondrites appear to have solidified directly from the original solar system cloud.**
  - **Iron meteorites, by contrast are mostly made of iron, and probably formed from the core of a large body that had undergone density differentiation.**
  - **Achondrites are a third kind. They may be more similar to the mantle.**

Diamonds and The Mantle



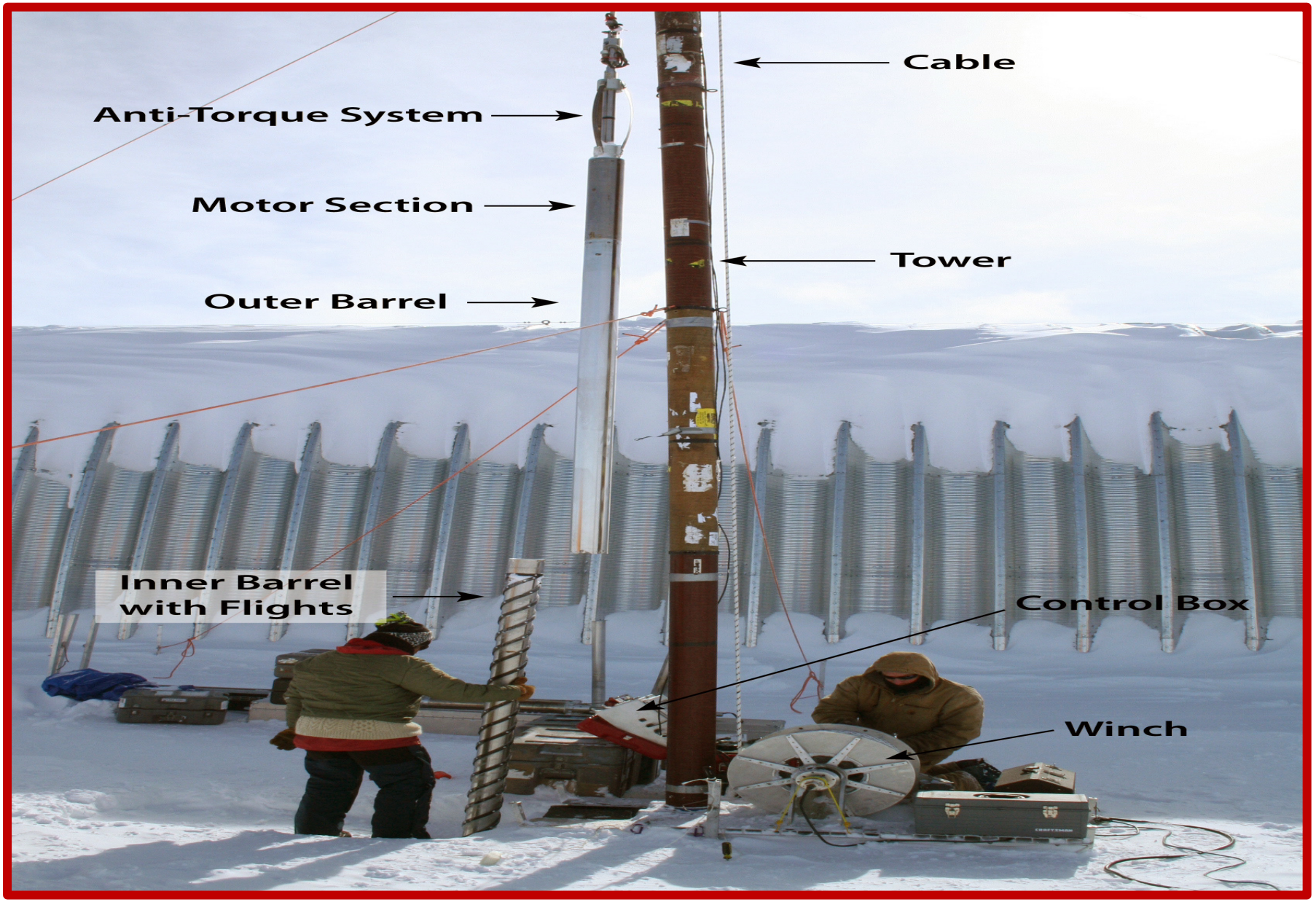
- **Kimberlite is a type of potassic volcanic rock best known for sometimes containing diamonds.**
- **Kimberlite pipes are the most important source of mined diamonds today.**
- **The consensus on kimberlites is that they are formed deep within the mantle. Formation occurs at depths between 93 and 280 miles.**
- **Kimberlites are the most important source of primary diamonds.**

"This is our most successful project. When we dug the footing for the wind turbine, we struck oil."

DRILLING OF ICE CORES & CLIMATE

The farther backward you can look,
the farther forward you are likely to see.
~ Winston Churchill

- The study of past CO2 levels and climates helps us understand the conditions in which human societies developed.
- This 'paleoclimate' information offers important lessons for understanding the range of climatic conditions that human societies are known to be suited for.
- Ice cores are the best source of atmospheric CO2 data for the prior 1 million years.
- Scientists analyze the cores to learn about past changes in the concentration of atmospheric gases and the glacial-interglacial cycles for the past million years.



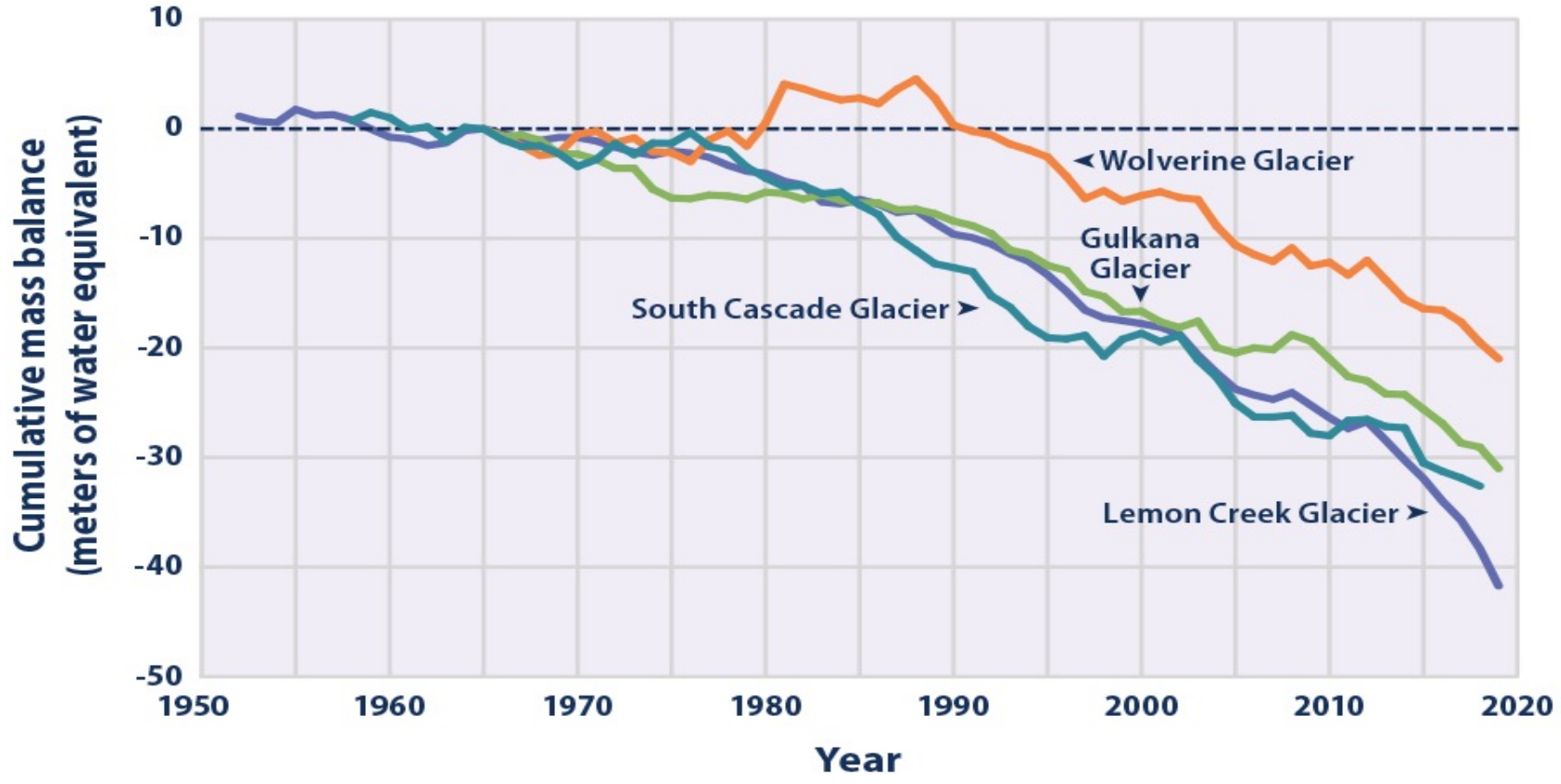
- Drillers at WAIS Divide, Antarctica use the 4-Inch electromechanical drill to collect an ice core.

The DISC Drill's sonde and tower tilt from vertical to horizontal to aid in the removal of the ice core and chips. In this image the tower and sonde are at a ~45° position inside the drill slot.

- By looking at past concentrations of greenhouse gasses in layers in ice cores, scientists calculate how modern amounts of carbon dioxide and methane compare to those of the past, and, essentially, compare past concentrations of greenhouse gasses to temperature.
  - ✓ They are essentially frozen time capsules that allow scientists to reconstruct climate far into the past. Layers in ice cores correspond to years and seasons, with the youngest ice at the top and the oldest ice at the bottom of the core.
- Atmospheric carbon dioxide levels are now 40% higher than before the industrial revolution.
  - ✓ The magnitude and rate of the recent increase are almost certainly unprecedented over the last 800,000 years.
  - ✓ Methane also shows a huge and unprecedented increase in concentration over the last two centuries.

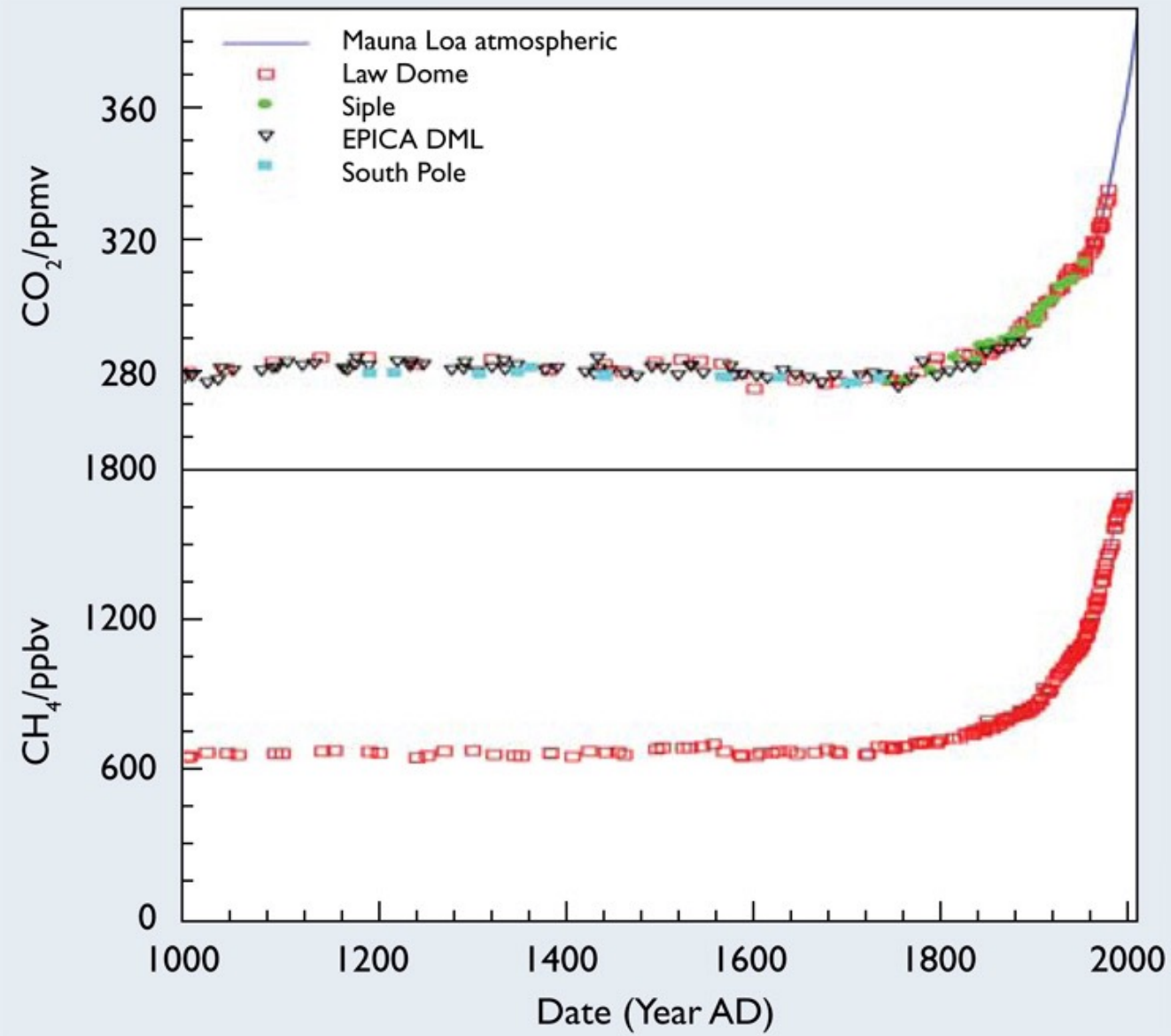
Each silver tube on these shelves contains a 1-meter long section of an ice core. The white boxes contain new ice cores drilled from the West Antarctic Ice Sheet (WAIS) Divide ice core site.

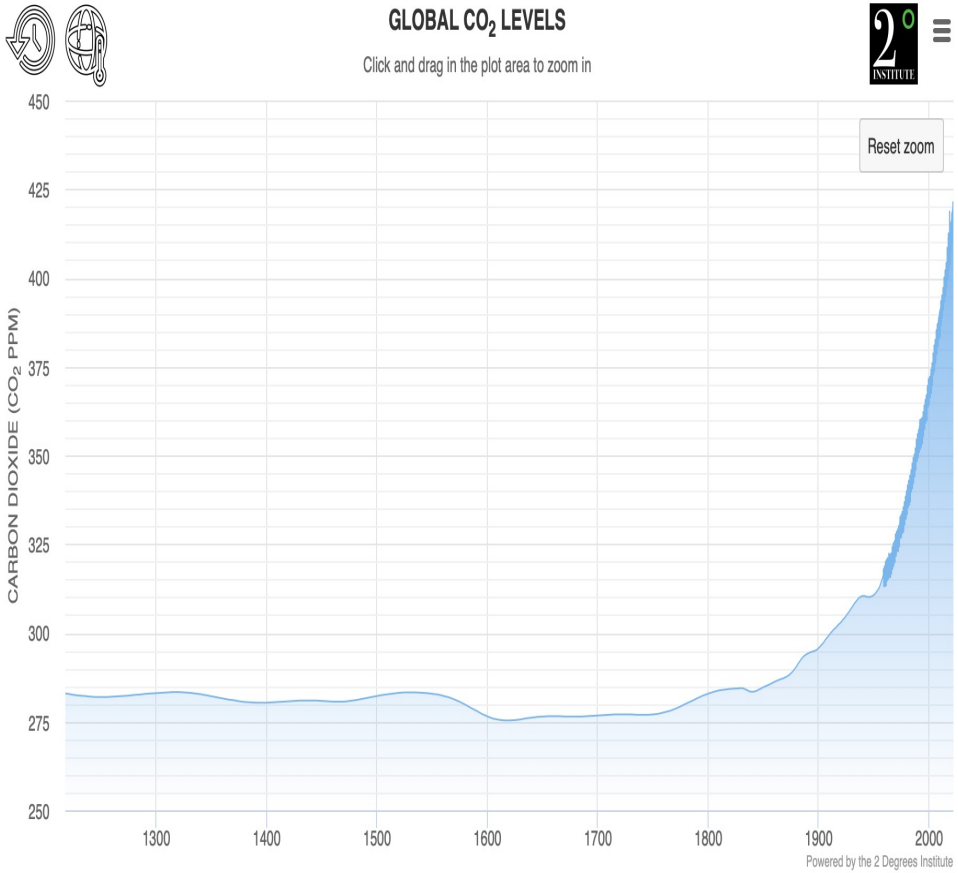
A race against time: Scientists are rushing to collect ice cores before glaciers melt

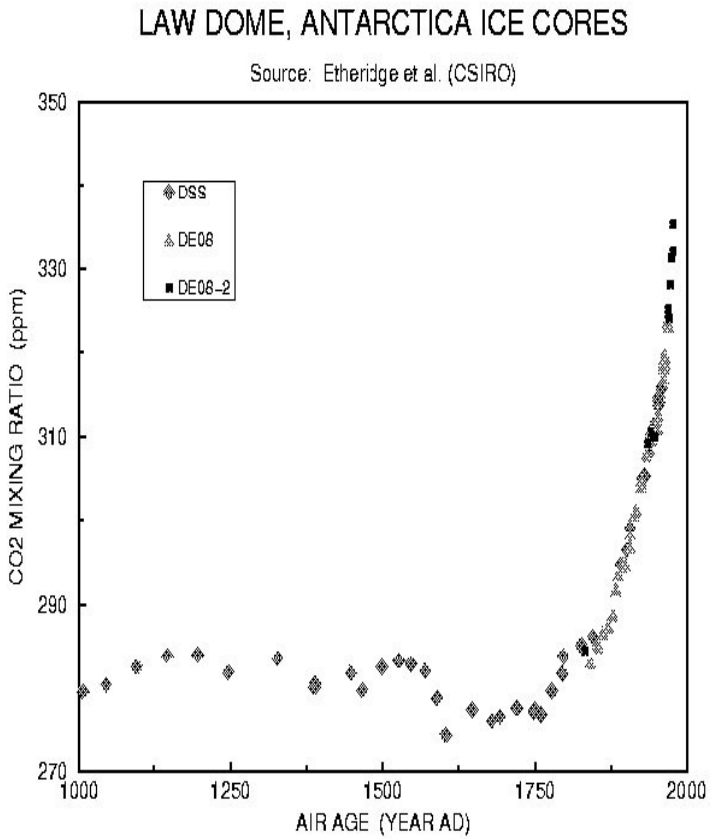


- This figure shows the cumulative mass balance of four U.S. reference glaciers since measurements began in the 1950s or 1960s.
- For each glacier, the mass balance is set at zero for the base year of 1965.
- Negative values indicate a net loss of ice and snow compared with the base year.

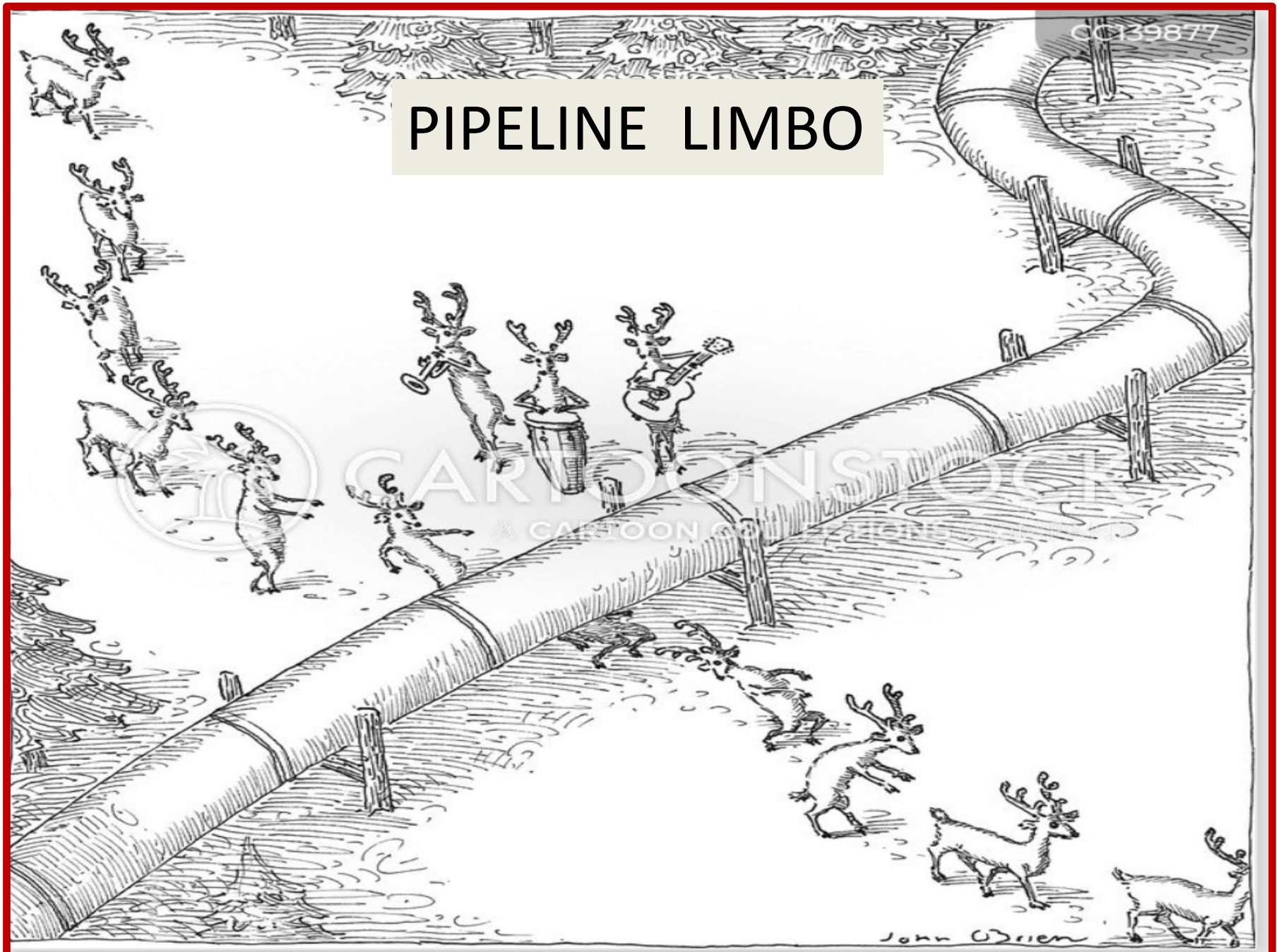
Fig. 2: *CO_2 and CH_4 over the last 1,000 years*[1-4]





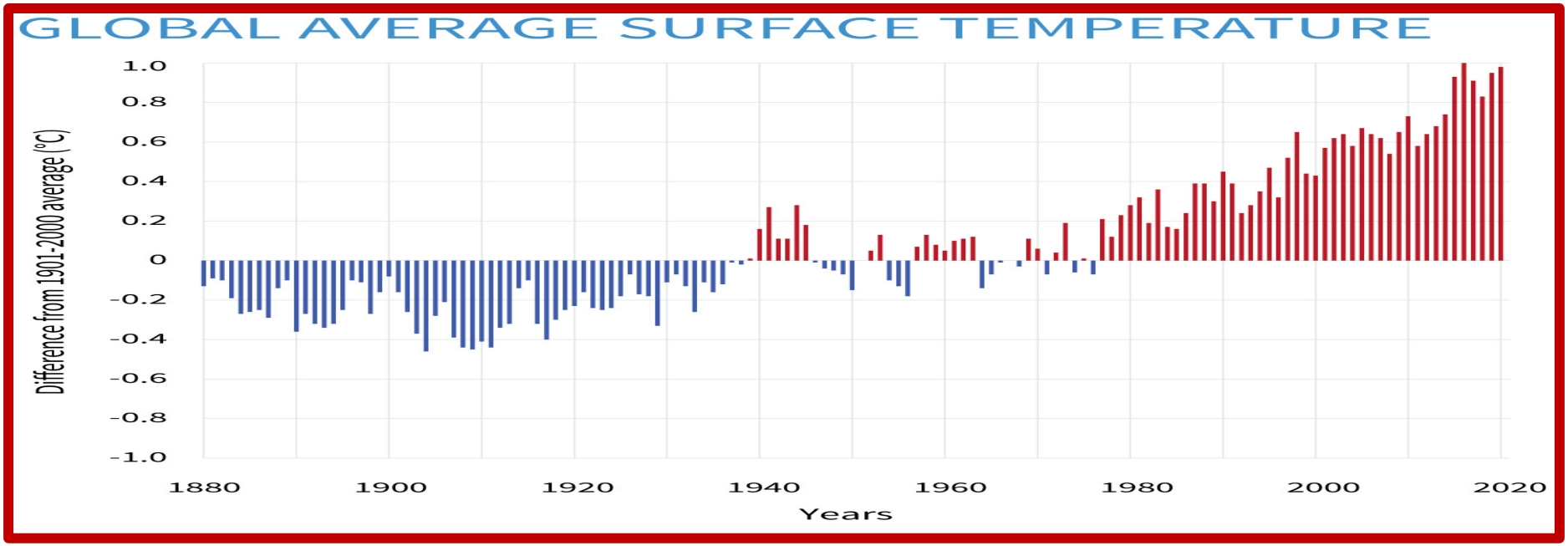


- Three ice cores drilled at Law Dome, East Antarctica from 1987 to 1993 resulted in atmospheric CO_2 records from 1006 A.D. to 1978 A.D.
- Pre-industrial CO_2 levels range from 275 to 284 ppm.
- Lower levels occurred between 1550 and 1800 A.D.
- These ice cores show major growth in atmospheric CO_2 levels in the industrial period except 1935-1945 A.D. when levels stabilized or decreased slightly.

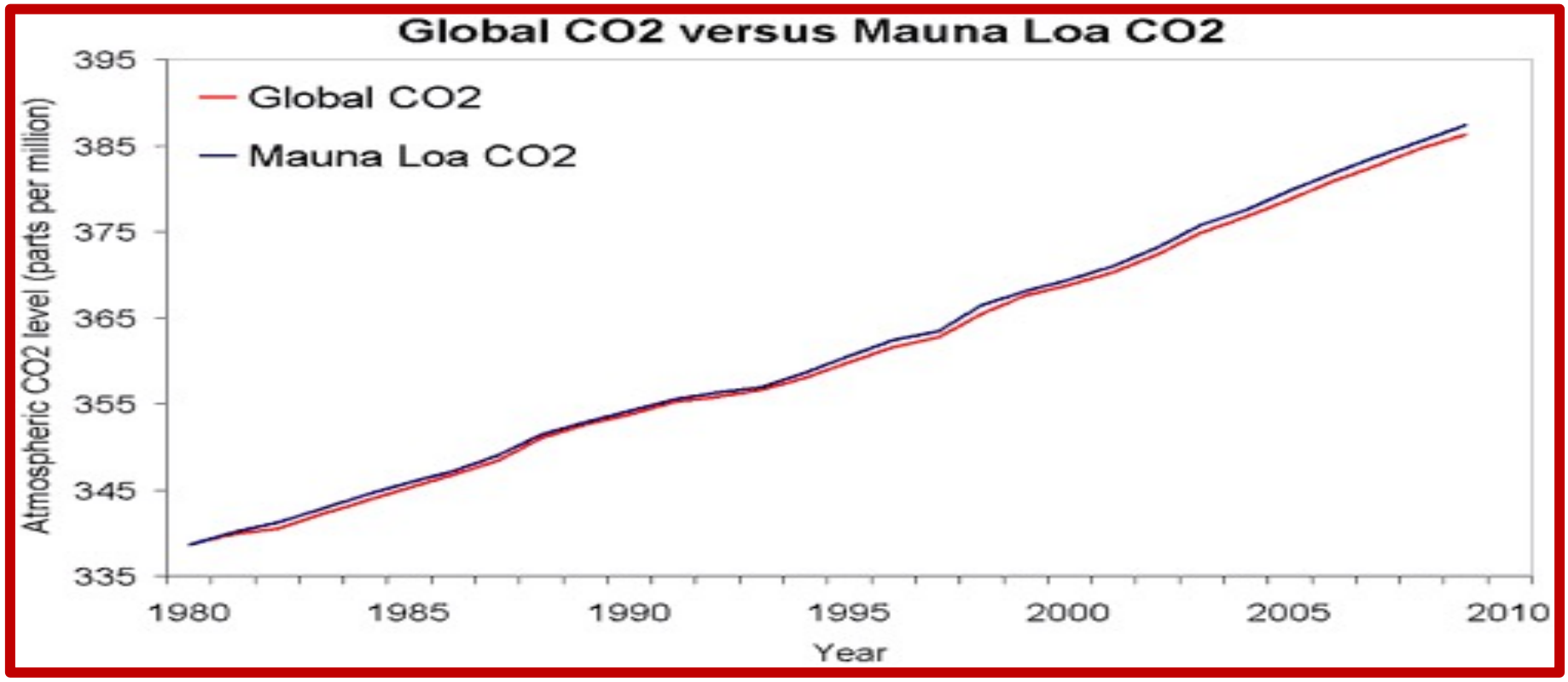

PIPELINE LIMBO
John O'Brien

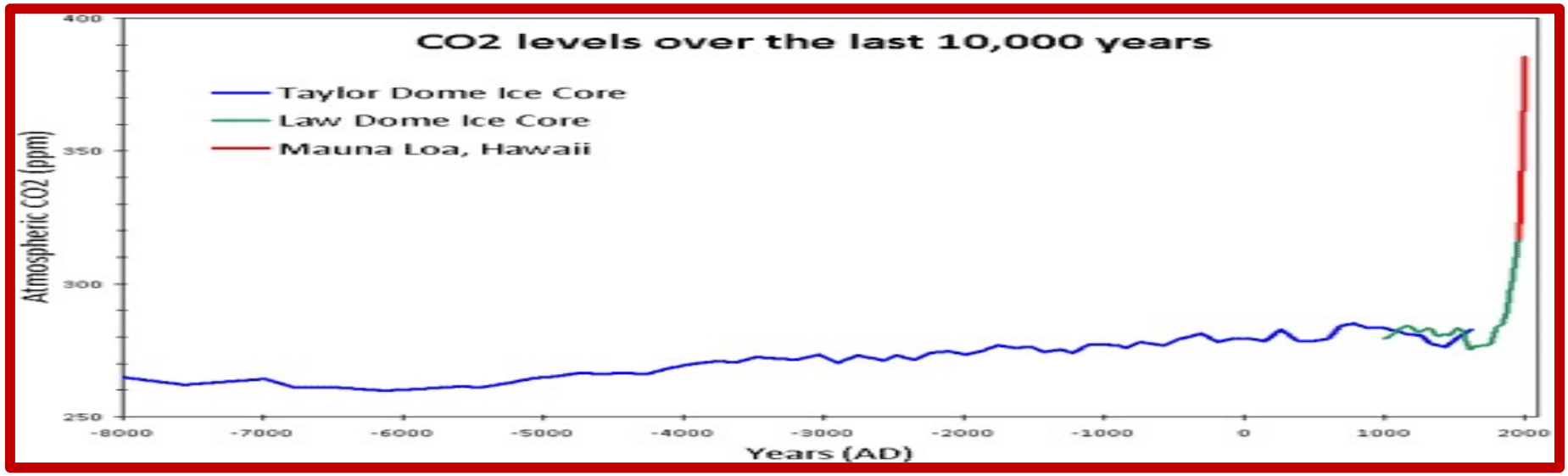
LATEST ON CLIMATE CHANGE

- **For years, the IPCC, governments and environmental organizations they influence have told the public:**
  - ✓ **that global warming is still manageable**
  - ✓ **that global warming consequences will occur gradually**
  - ✓ **that global warming consequences will remain generally mild until about 2100**
  - ✓ **the very worst consequences of global warming will occur after 2100 long after most of us living today are gone.**
- **Nothing listed in items 1-4 above could be farther from the truth!**
  - ✓ **The public has no idea that we have managed global warming *so incredibly poorly* for the last 35 plus years that it has probably now become *out of our meaningful control* for at least *another* 30-50 years with horrific and unavoidable consequences arriving *far sooner* than almost any of us are prepared to deal with.**
  - ✓ **It's also far worse than just now *unavoidable* horrible consequences. What we do now until 2025 will be critical in determining if we are able to avoid the *likelihood* of extinction.**



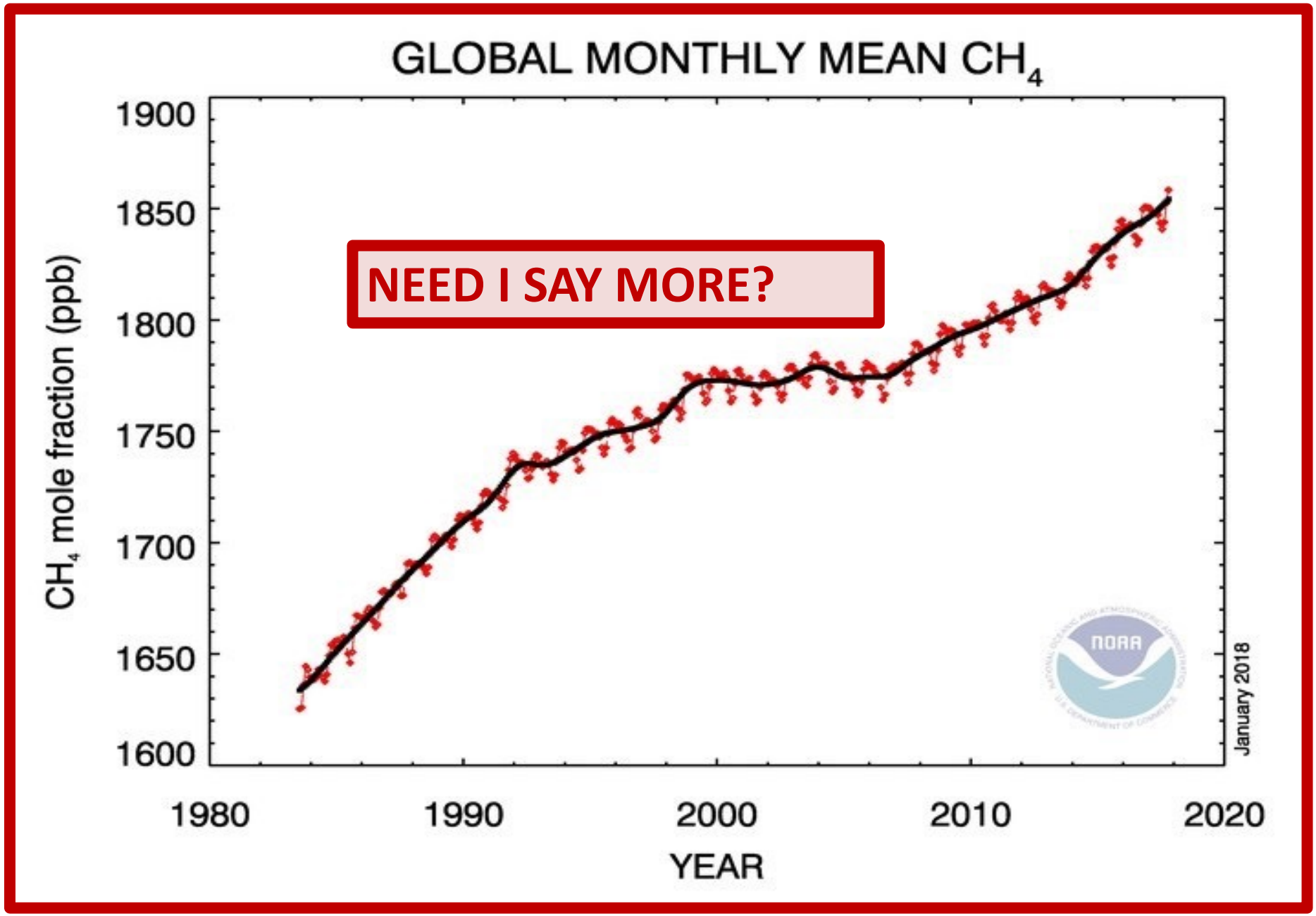
- **Earth's temperature has risen by 0.14° F per decade since 1880, and the rate of warming over the past 40 years is more than twice that: 0.32° F per decade since 1981.**
- **Despite a late-year La Niña event that cooled a wide swath of the tropical Pacific Ocean, 2020 came just 0.04˚ Fahrenheit shy of tying 2016 for warmest year on record.**
- **The 10 warmest years on record have occurred since 2005.**
- **From 1900 to 1980 a new temperature record was set on average every 13.5 years; from 1981–2019, a new record was set every 3 years.**


Global CO2 versus Mauna Loa CO2
Global CO2
Mauna Loa CO2
Atmospheric CO2 level (parts per million)
395
385
375
365
355
345
335
1980
1985
1990
1995
2000
2005
2010
Year


CO2 levels over the last 10,000 years
Taylor Dome Ice Core
Law Dome Ice Core
Mauna Loa, Hawaii
Atmospheric CO2 (ppm)
400
350
300
250
-8000
-7000
-6000
-5000
-4000
-3000
-2000
-1000
0
1000
2000
Years (AD)

The world is banking on giant carbon-sucking fans to clean our climate mess. It's a big risk.

- **Hellisheiðarvirkjun, Iceland:** Machines like this are being used to literally suck the gas back out, like giant vacuum cleaners, in an attempt to slow the climate crisis and prevent some of its most devastating consequences.
- The Orca plant is a "direct air carbon capture facility," and its creators and operators say it's the world's largest.
- It opened last month and currently removes the amount of carbon emitted by 800 cars a day in the US.
- It's also about the same amount of carbon 500 trees could soak up in a year.
- It's a fine start, but in the grand scheme of things, its impact so far is miniscule. Humans emit around 35 billion tons of greenhouse gas a year..

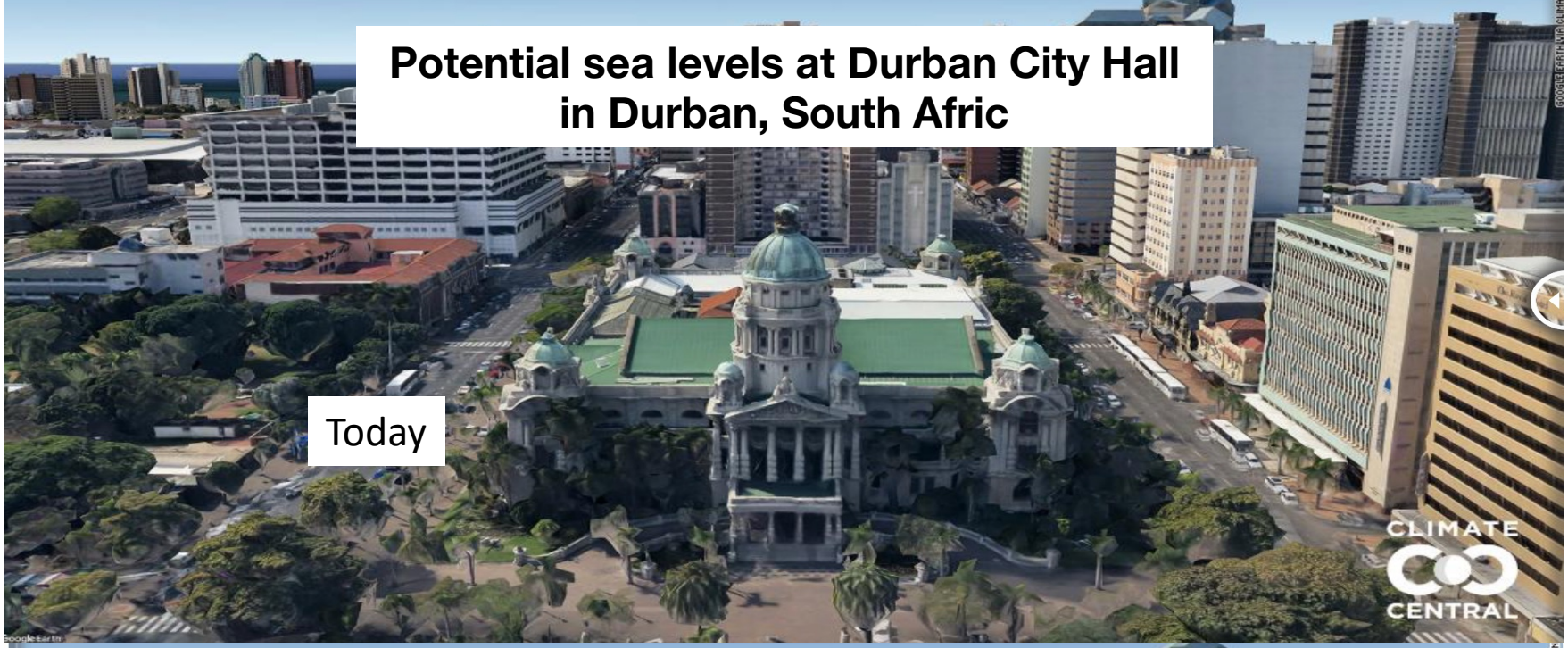

GLOBAL MONTHLY MEAN CH_4
NEED I SAY MORE?
CH_4 mole fraction (ppb)
1900
1850
1800
1750
1700
1650
1600
1980
1990
2000
2010
2020
YEAR
NOAA
January 2018

- Many studies have estimated that leaks from oil and gas production, particularly fracking, are a major driver of rising methane emissions.
- After a very deep dive into multiple ground and satellite datasets, NASA determined that there is a third source of methane emissions — global fires.
- STAY TUNED! My next lecture (*January 22, 2022*) will be on Methane issues.

America is building another big wall. This one will protect New York

- By 2025, New York's Staten Island will be fortified by a towering seawall running 5.3 miles along the coast, an engineering feat designed to ward off a growing threat.
- The climate crisis is predicted to create more powerful and extreme weather systems all over the world, and coastal engineers are racing to respond with structures to reduce their impact.

Potential sea levels at Durban City Hall in Durban, South Afric



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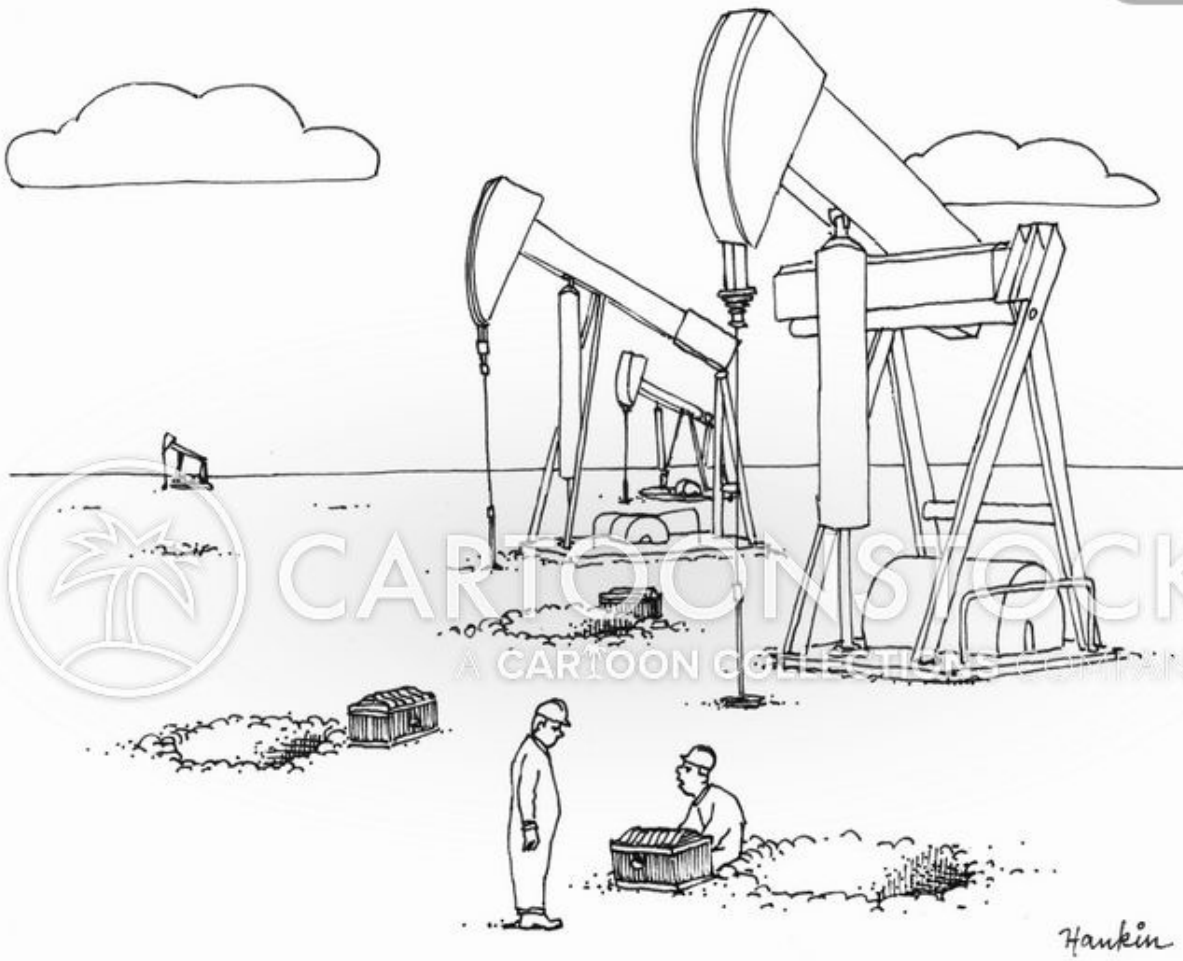

"They're full of solar panels."

Charlie Hankin and Andrew Ocean

What We Talked About

- Types of Wells
  - ✓ Injection Wells
  - ✓ Extraction Wells
    - ➢ Core Drilling in Rock
  - ✓ Fracking
- Fracking + and --
- The Earth's Interior:
  - ✓ What's our best guess?
  - ✓ What are our "best guessing" tools?
- Core Drilling in Ice
- Latest on Climate Change

POP QUIZ ANSWERS

A. Putting something into the ground.

1. What types of wells are used for A?

Injection Wells - An injection well is used to place fluid underground into porous geologic formations.

- ✓ What is put into the earth using your answer to 1?

Injected fluids may include water, wastewater, brine (salt water), water mixed with chemicals, radioactive fluids, CO_2.

B. Taking something out of the ground.

2. What types of wells are used for B?

Extraction Wells - Used to extract fluids (oil, water) or solids (core samples) from the ground.

- ✓ What is taken out of the earth using your answer to 2?

Natural resource such as ground water, brine, natural gas, or petroleum

Drilling for the exploration of the nature of the material underground (for instance in search of metallic ore) is best described as borehole or core drilling.

POP QUIZ ANSWERS

C. Putting something in AND taking something out

3. What types of wells are used for C?

Fracking Wells - Wells are drilled, fluids forced in under pressure, gas is extracted.

✓ What is put in and take out the earth using your answer to 3

The process involves the high-pressure injection of "fracking fluid" into a wellbore to create cracks in the deep-rock formations through which natural gas, petroleum, and brine will flow more freely. When the hydraulic pressure is removed from the well, small grains of hydraulic fracturing proppants(either sand or aluminium oxide) hold the fractures open.

Methane's Role in Climate Change

- ✓ *Methane is widely recognized as one of the worst greenhouse gases contributing to climate change.*
- ✓ *Methane independently functions as a powerful accelerant of greater atmospheric heating, faster ice melt, more severe weather disturbances, ocean acidification, and rising seas.*
- ✓ *This threat, and what is being done to mitigate it, will be the subject of this class*

January 22, 2022 10:00 AM
Zoom