Remote Sensing and Non-renewable Energy Resources

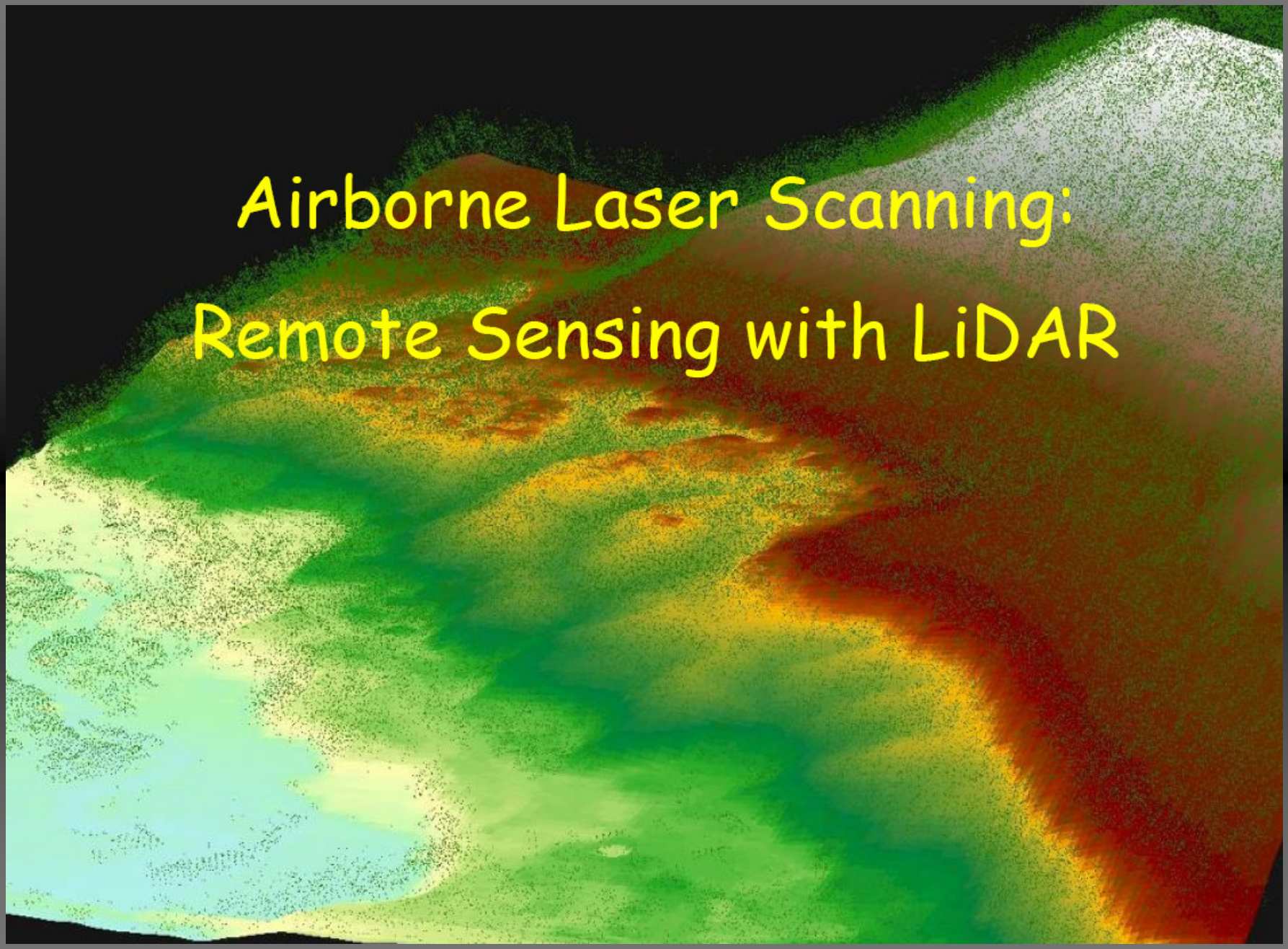
A presentation by Gregory Herman, TCNJ 2015 adapted from prior presentations by Karl Muessig, the University of West Florida, and Exxon-Mobil Corp

Common and important aspects of remote sensing in Geology

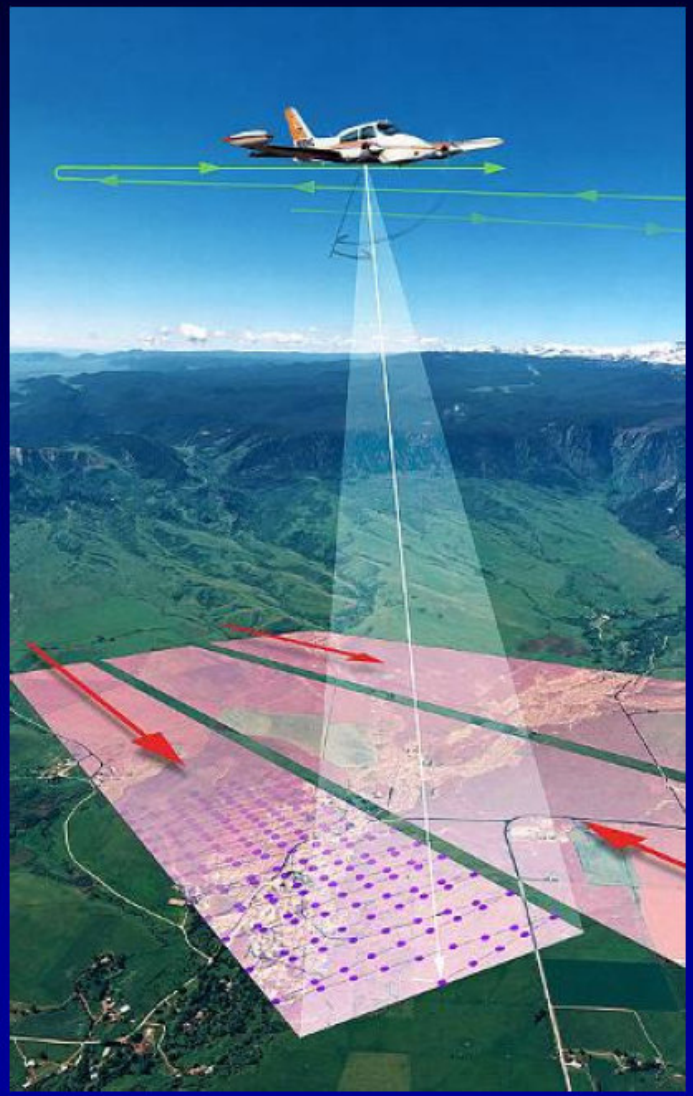
- Spectroscopy
- LiDAR – Light detection and ranging (using laser sources)
- Shallow subsurface geophysics including borehole logging
- Crustal seismic-reflection profiling
- An emerging market – drone facilitated near-surface geophysics

Airborne Laser Scanning:

Remote Sensing with LiDAR



Airborne Laser Scanning



- ALS/LiDAR is an active remote sensing technology that measures distance with reflected laser light.
- LiDAR: LIght Detection and Ranging or Laser Imaging Detection and Ranging)
- 1st developed in 1960 by Hughes Aircraft inc.
- Modern computers and DGPS make it practical.
- Typically used in very accurate mapping of topography.
- New technologies and applications are currently being developed.

Why use a Laser?

ALS systems take advantage of two of the unique properties of laser light:

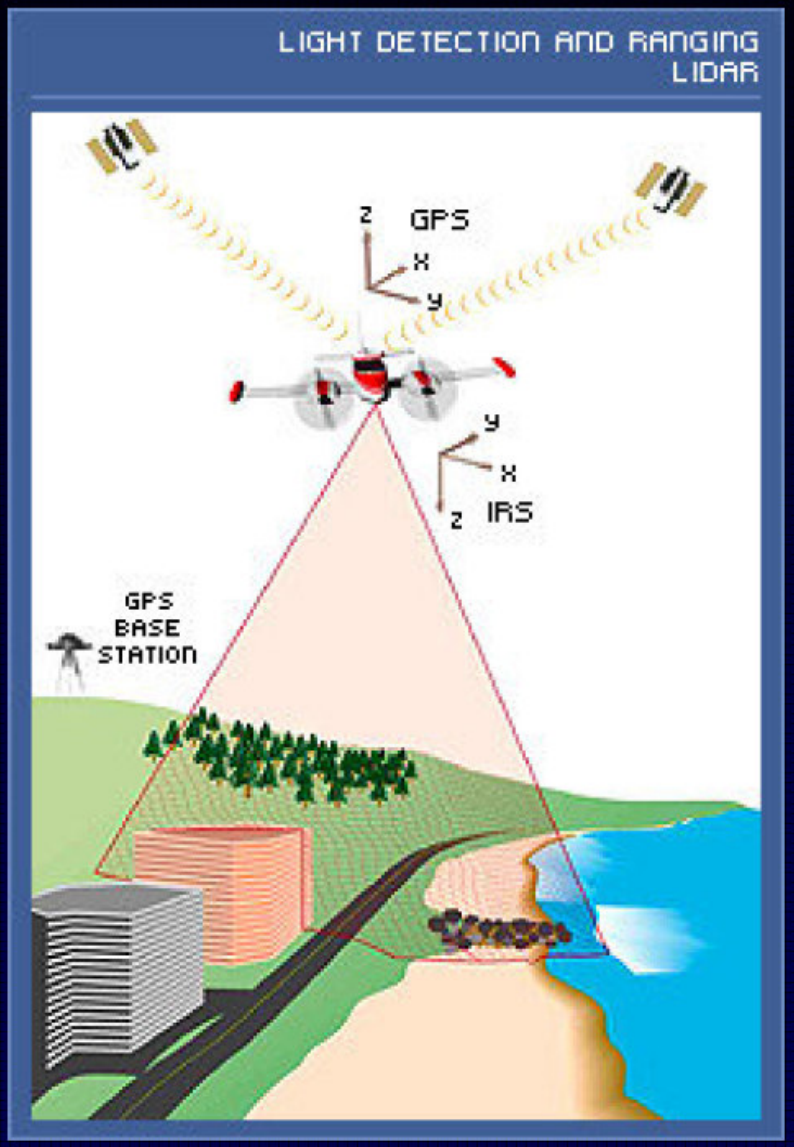
1. The laser is **monochromatic**. It is one specific wavelength of light. The wavelength of light is determined by the lasing material used.

Advantage: We know how specific wavelengths interact with the atmosphere and with materials.

2. The light is very **directional**. A laser has a very narrow beam which remains concentrated over long distances. A flashlight (or Radar) on the other hand, releases energy in many directions, and the energy is weakened by diffusion.

Advantage: The beam maintains its strength over long distances.

3mrad divergence = 30 cm at 1 km and 1.5m at 5 km.



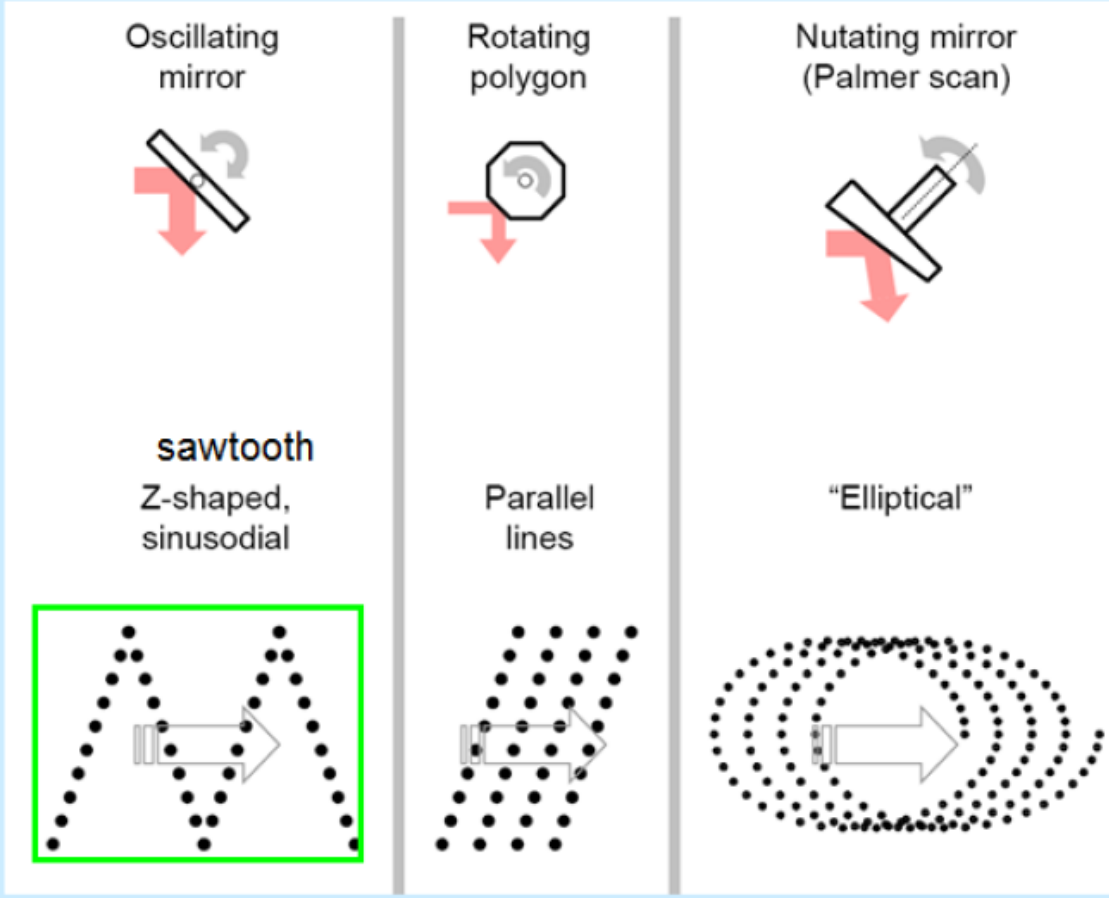
ALS mapping concepts

- The position of the aircraft is known (from DGPS and IMU-Inertial Measurement Unit).
- Measures distance to surfaces by timing the outgoing laser pulse and the corresponding return (s).
- Distance = time*(speed of light)/2
- By keeping track of the angle at which the laser was fired: you can calculate the X, Y, Z position of each “return”.
- Requires extremely accurate timing and a very fast computer.

Scanning Mechanisms

Mechanism

Ground pattern



Most common pattern
(Leica, Optech)

Two Distinct Families of ALS Systems

Waveform systems (a.k.a. large-footprint)

Records the **COMPLETE** range of the energy pulse (intensity) reflected by surfaces in the vertical dimension.

Samples transects in the horizontal (X,Y) plane.

Waveform systems designed to capture vegetation information are not widely available.

Waveform systems include SHOALS, SLICER, LVIS, ICESat.

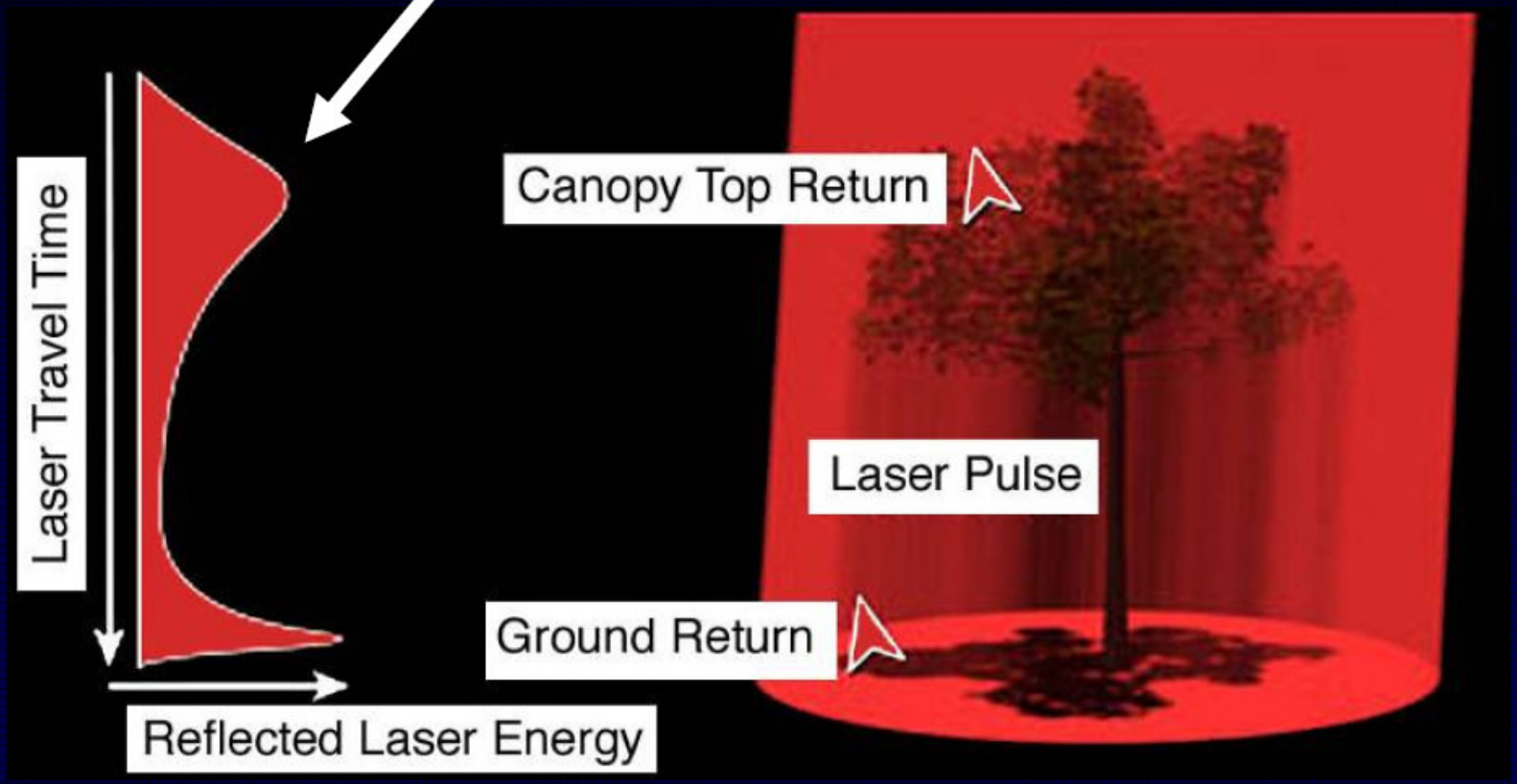
Discrete-return systems (a.k.a. small-footprint or topographic)

SAMPLES the returned energy from each outgoing laser pulse in the vertical plane (Z) *(if the return reflection is strong enough).*

Most commercial lidar systems are discrete return, many different types are available.

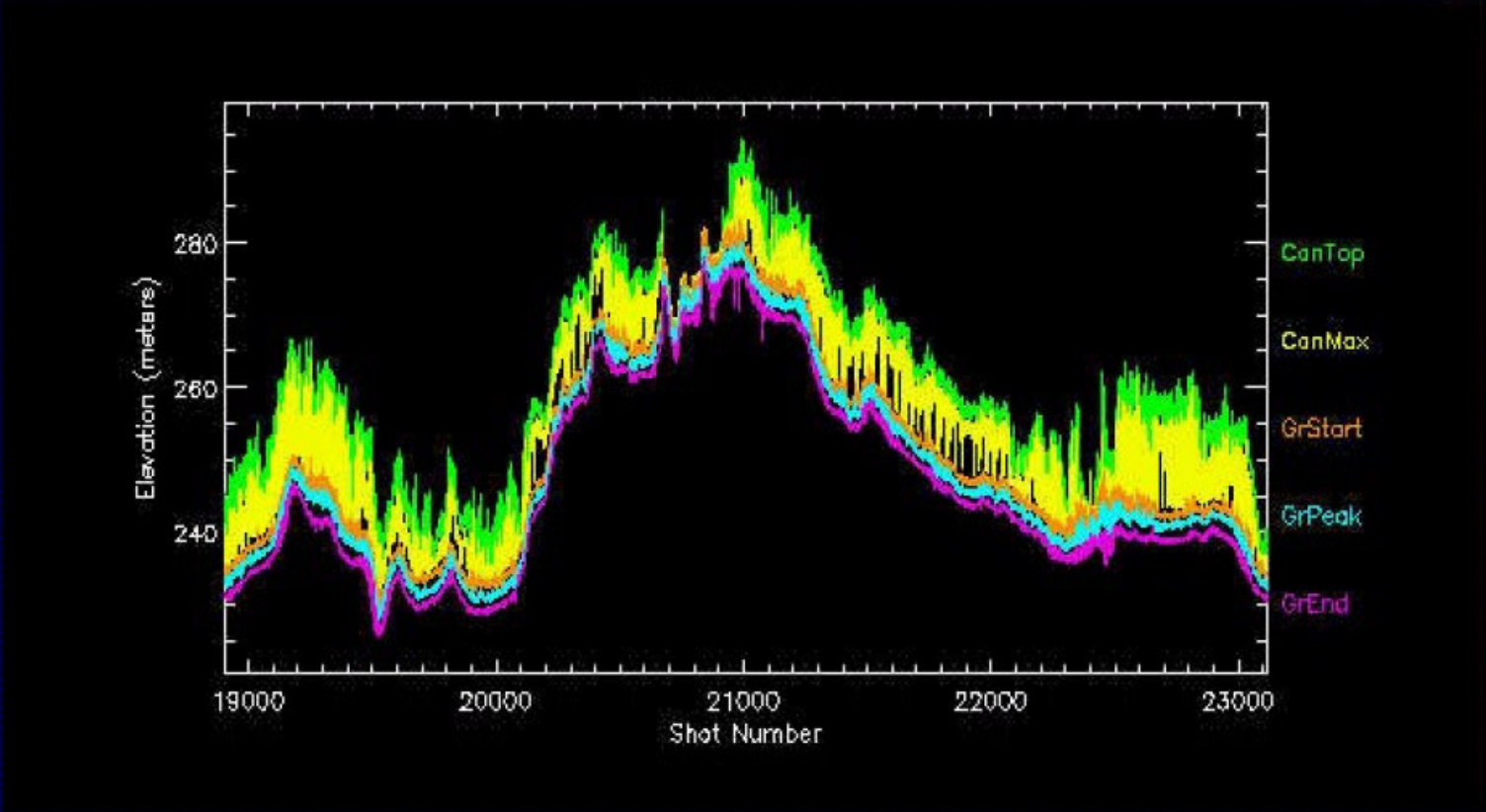
Waveform LIDAR

This is the "waveform" graph of energy intensity



Notice that it follows the "shape" of the tree biomass

Waveform LIDAR: SLICER



Waveform systems have been used to accurately measure (r^2 >.90) vertical distribution of tropical and temperate forests *(Lefsky 2001)*

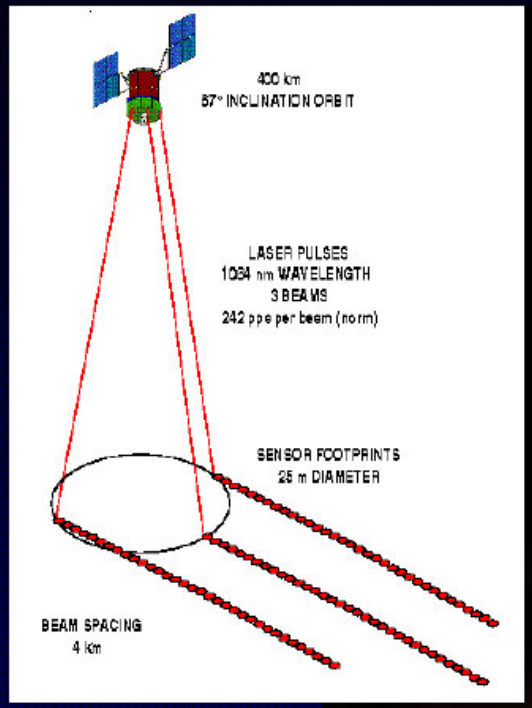
Spaceborne LIDAR: ICEsat and VCL

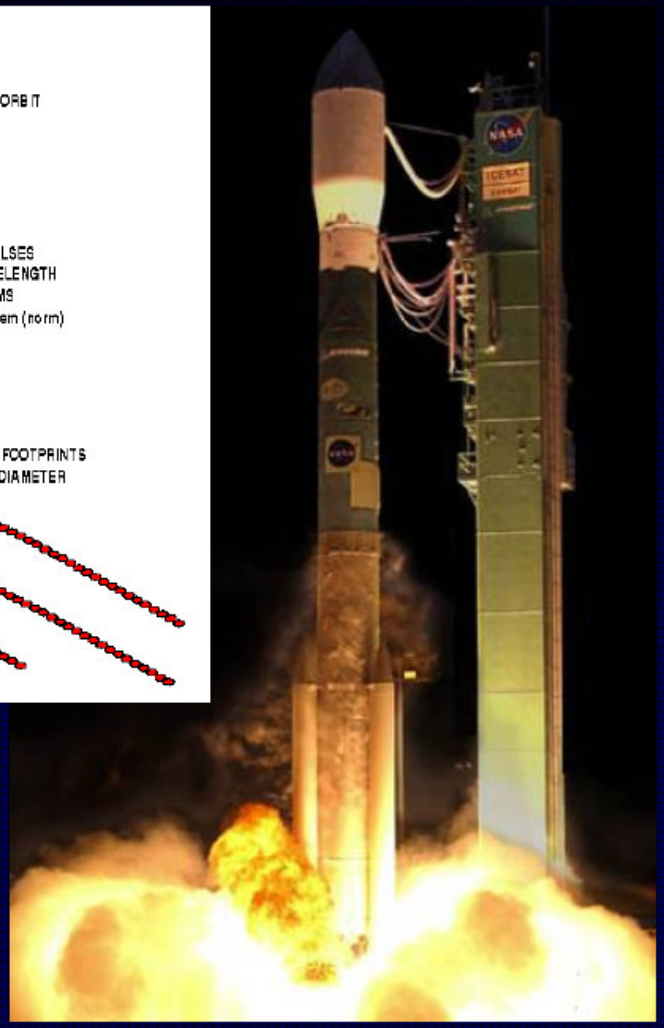
Spaceborne waveform LIDAR systems.

ICEsat launched in 2003 for survey of topography and polar ice.

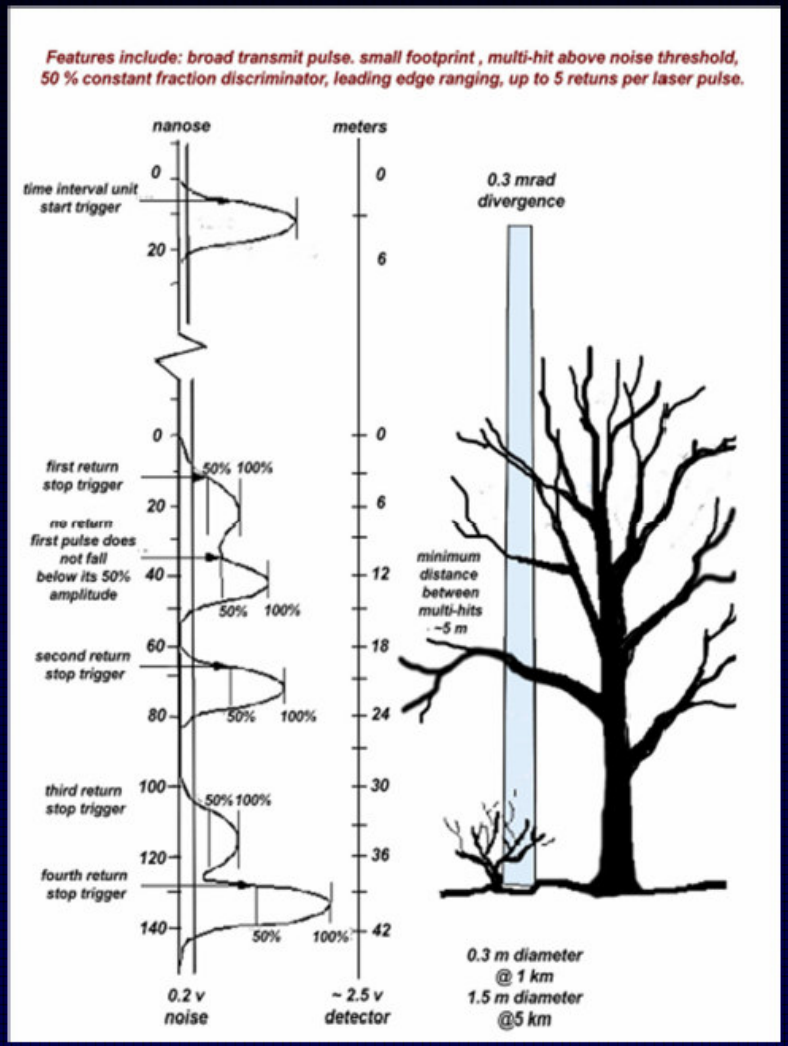
VCL (Vegetation Canopy LIDAR) was designed to sample 5 separate widely spaced tracks with 25m footprint waveforms. Has been cancelled.

Do not provide "wall to wall" mapping.



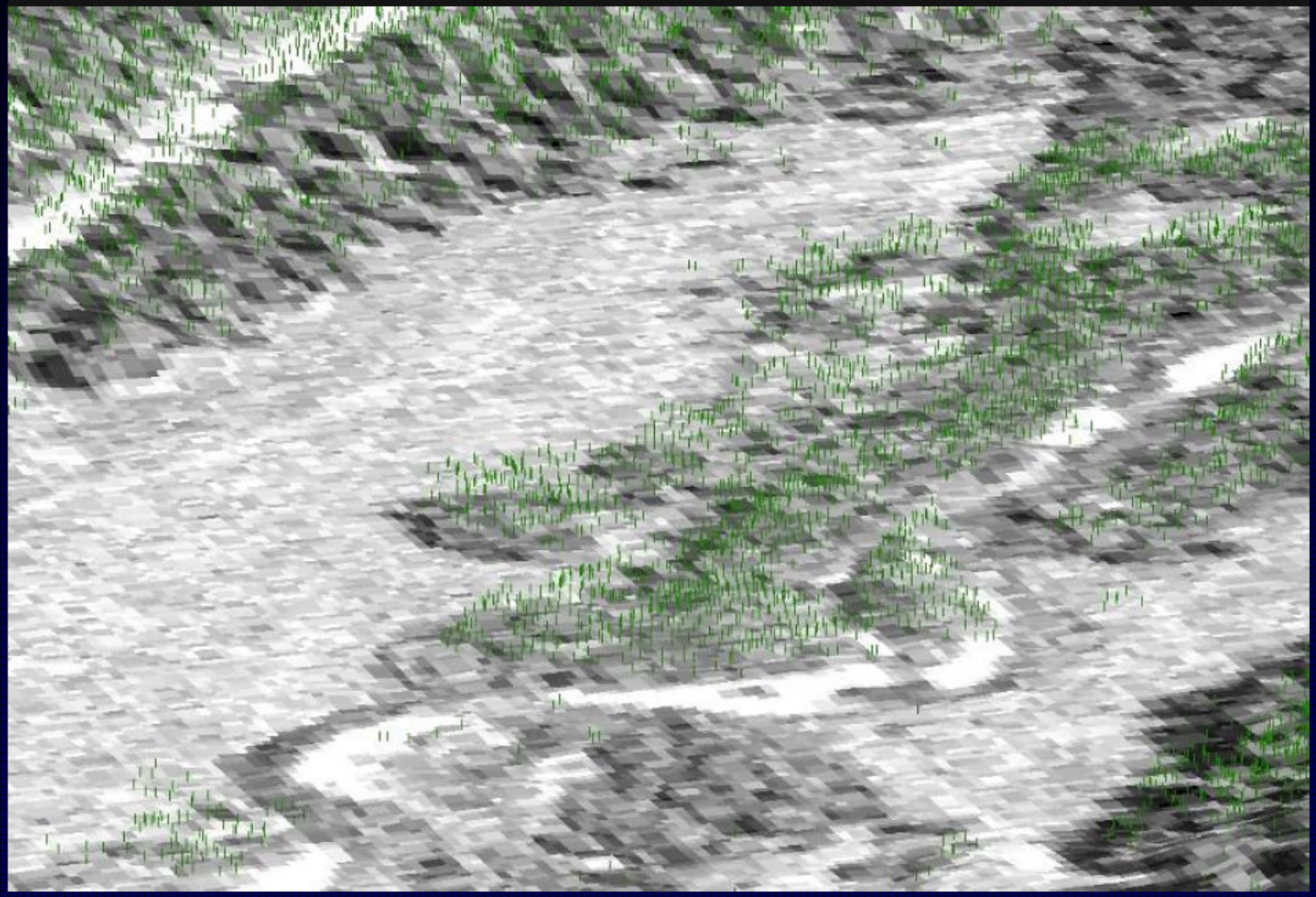


Discrete-return LIDAR



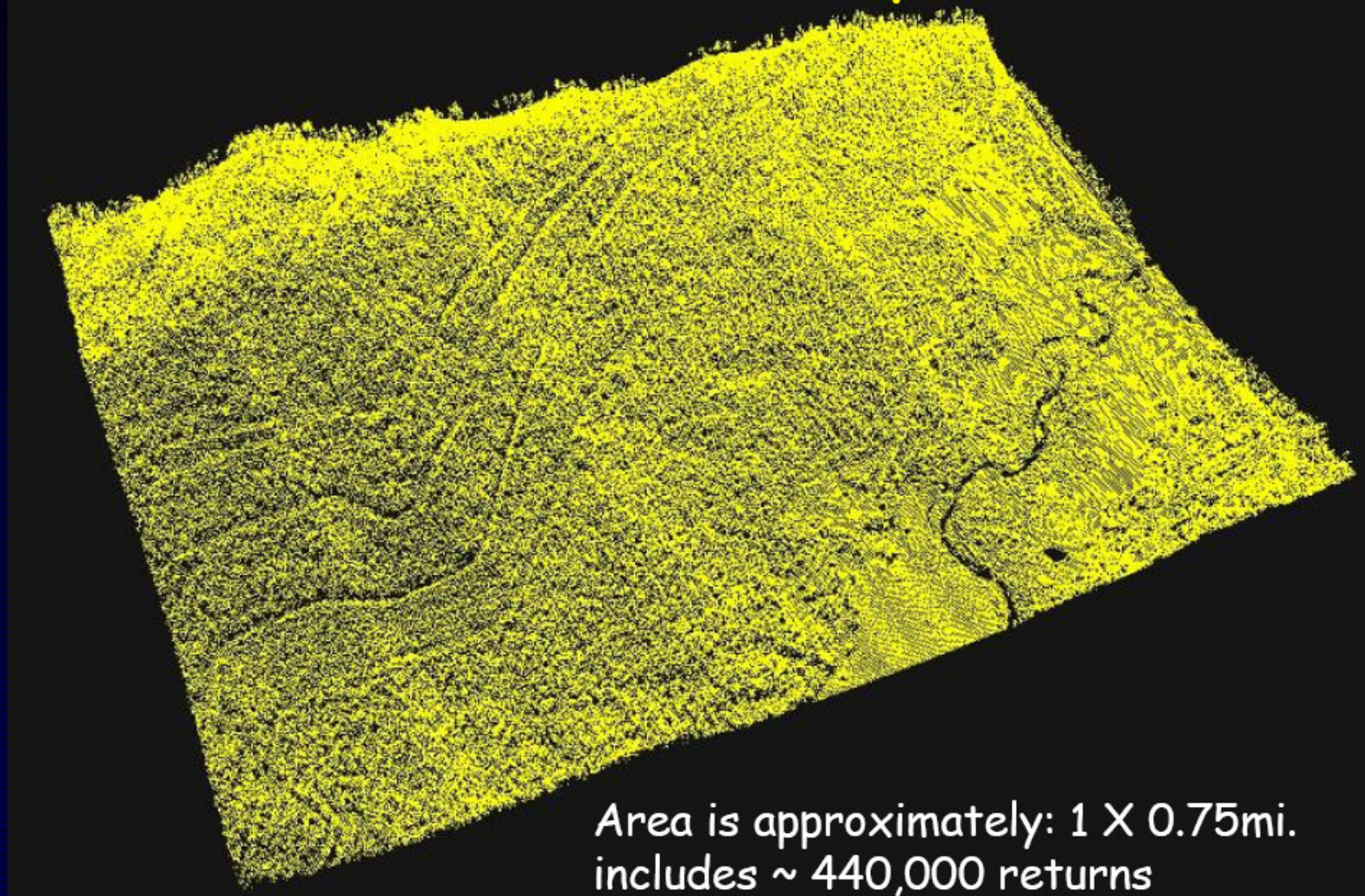
- Records data as X,Y,Z points.
- Spatial resolution is expressed in terms of "post spacing" which is the avg. horizontal distance between points.
- Returns are "triggered" if the laser reflects from a surface large enough to exceed a pre-set energy threshold.
- Minimum vertical distance between returns is ~ 5 meters.
- New capability to record the intensity of point returns.

LIDAR Captures 3D Structure Information



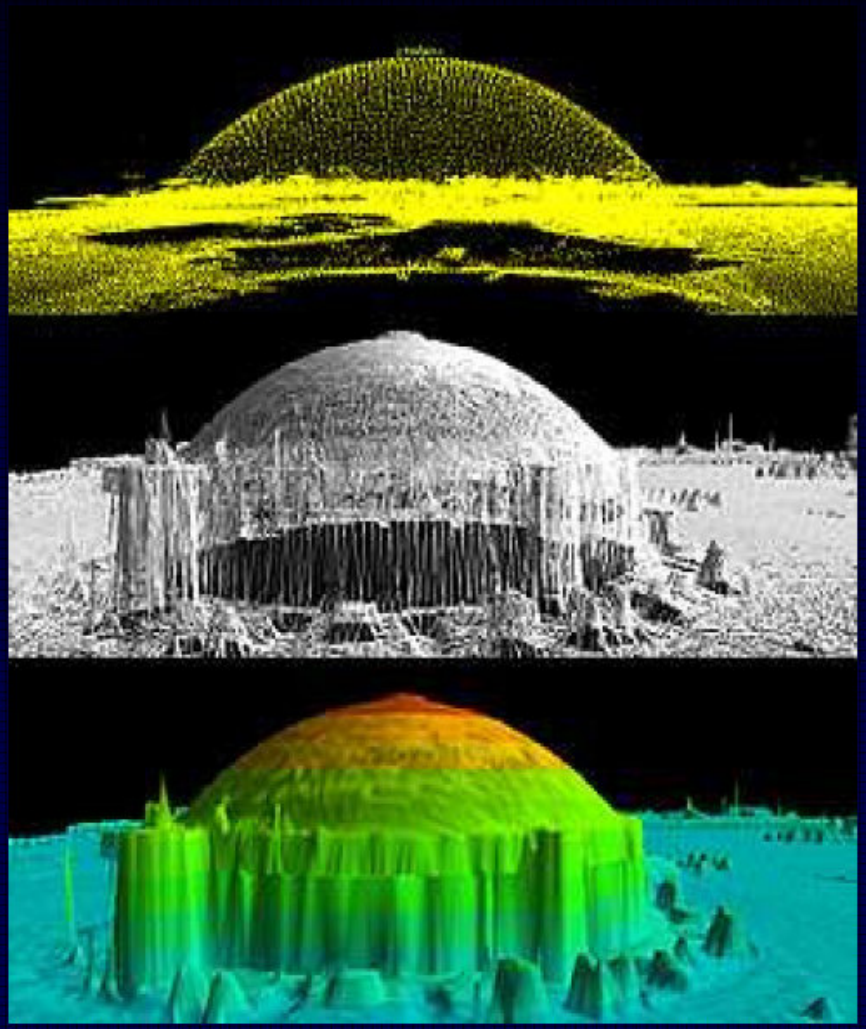
Discrete Return Data:

Millions of X,Y,Z points



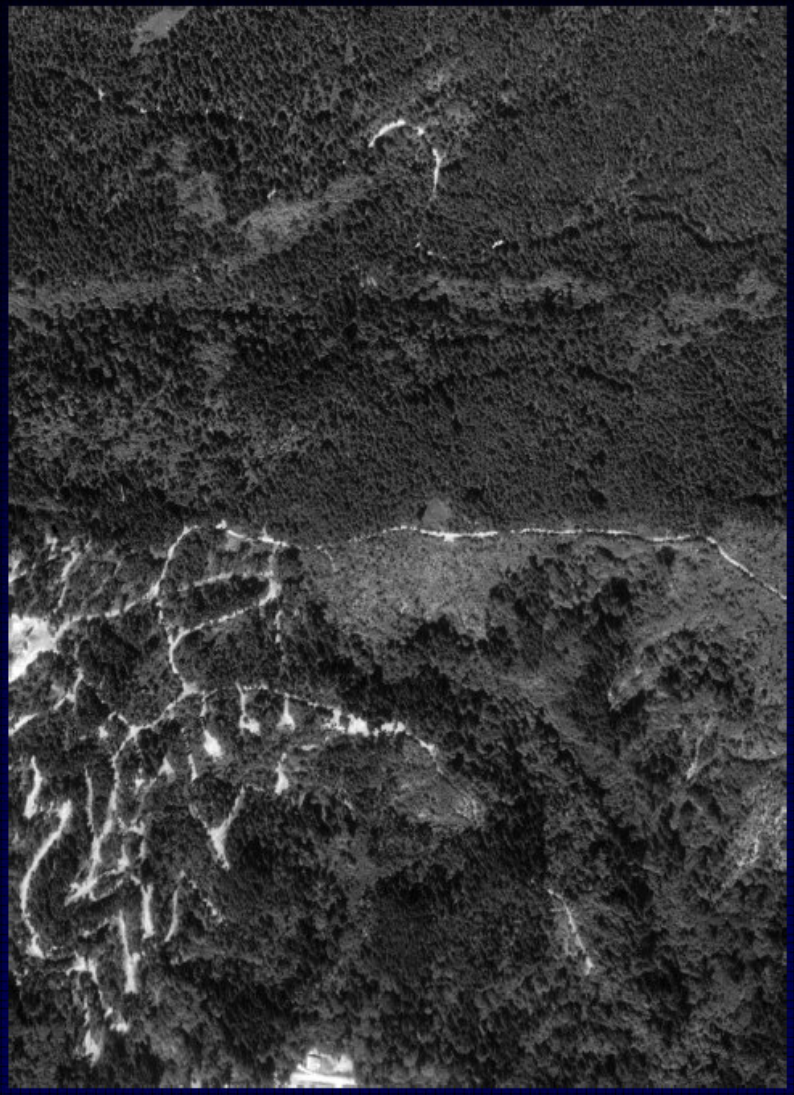
Area is approximately: 1 X 0.75mi.
includes ~ 440,000 returns

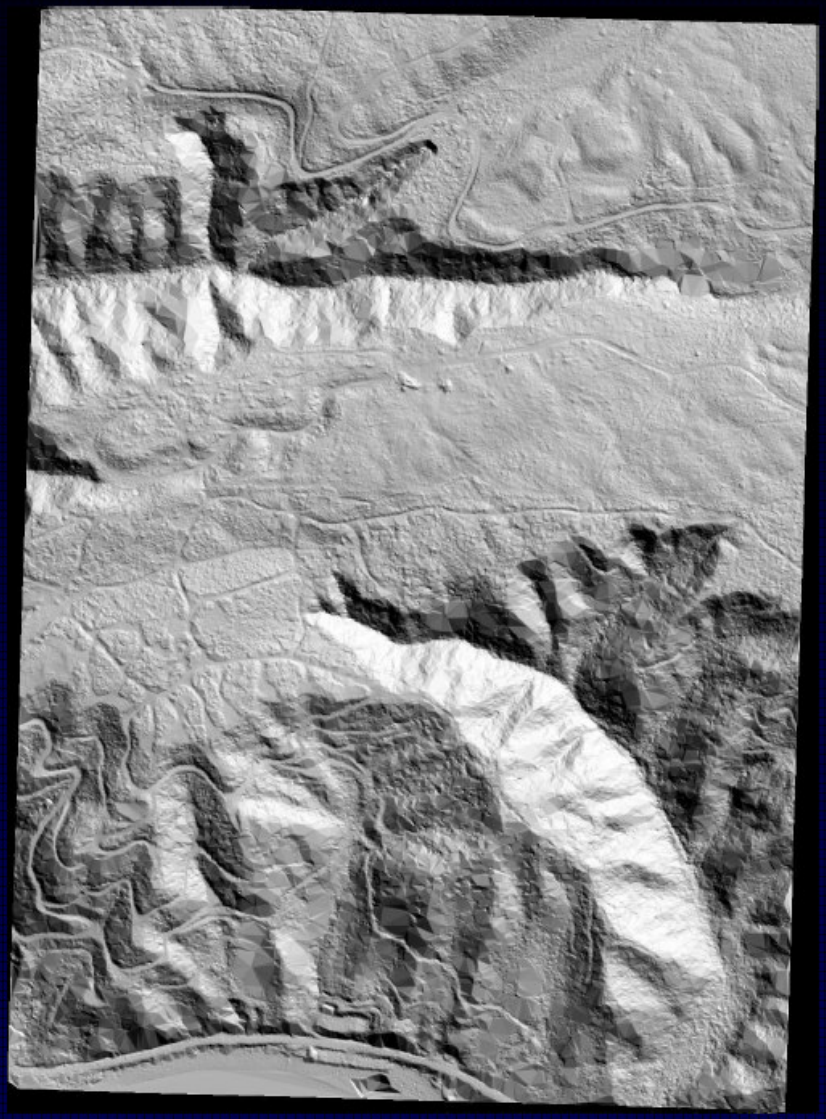
From Point Clouds to 3-D Surface Models



- Points are used to create 3D surface models for applications.
- Triangular Irregular Networks (TIN)s are used to classify the points and to develop Digital Elevation Models (DEM)s.
- Points must be classified before use: "bare earth" points hit the "ground"; other point categories include tree canopy and buildings.
- Correct identification of "bare earth" is critical for any lidar mapping application.

LIDAR Surfacing



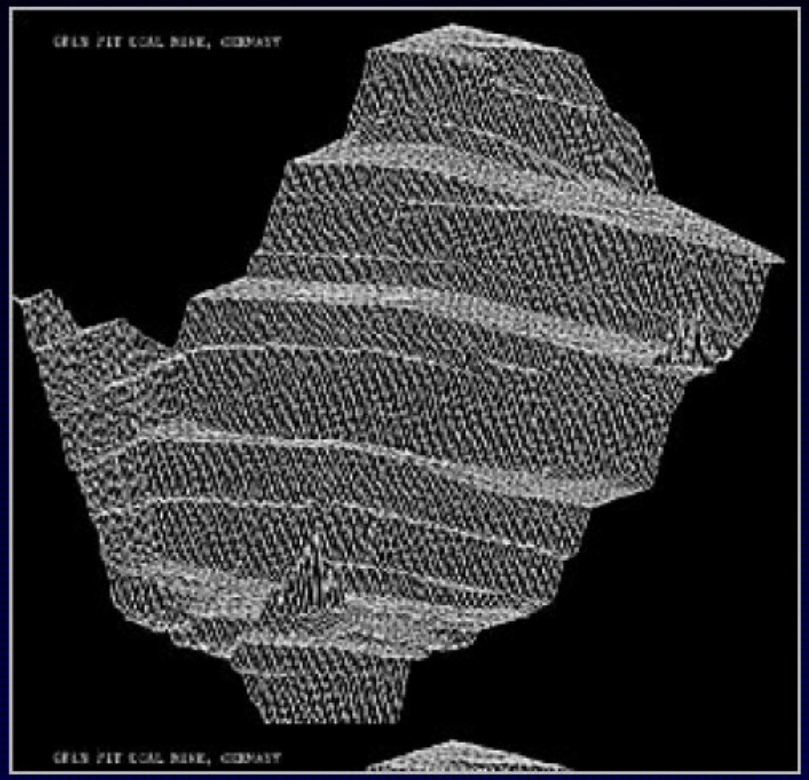


Applications

Detailed topographic mapping
Coastal areas – change / flooding
Linear disturbance – pipelines, power lines
Geological fault lines
Landslides
Forestry – biomass, canopy height, leaf area
Bathymetric – depth and surface layer biomass
3D urban mapping
Glacier elevation and change
Atmospheric – clouds, gases

Most common wavelength:	1064 nm (Near IR)
Bathymetric surveys:	532 nm (green)

Other Applications



Measuring volume change in open pit mines.

Utilities use lidar to map power transmission line curvature and clearance.

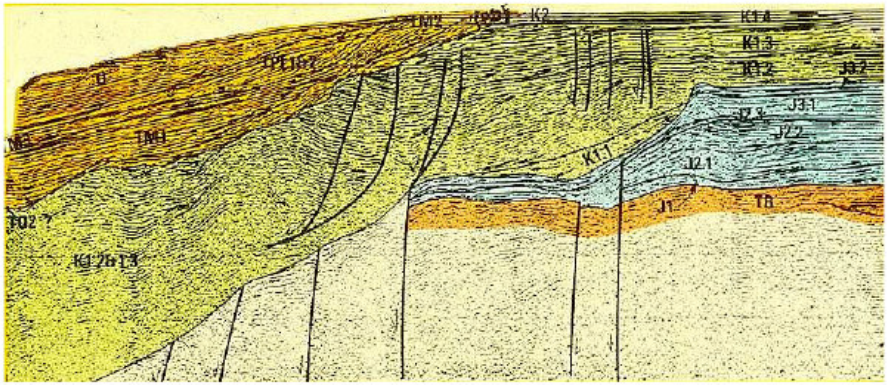
The Future of ALS

ALS/LIDAR technology is evolving rapidly, the next 10 years will bring many new capabilities and applications.

- Systems now available record 50,000 pps. Expect to see 100,000 pps systems soon.
- Automatic merging of multi-spectral imagery with LIDAR is being developed now.
- Laser induced fluorescence and measurement of changes in laser coherence and polarization will provide more information about the surfaces that the laser light interacts with.
- Look for multi-spectral LiDAR using multiple lasers in different frequencies recording intensity to spectrally identify surface materials.

Crustal seismic-reflection profiling

The Seismic Reflection Method



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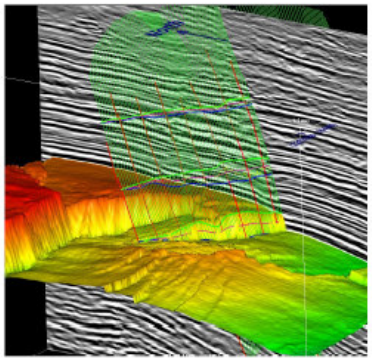
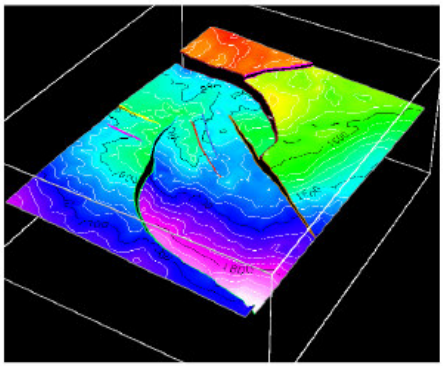
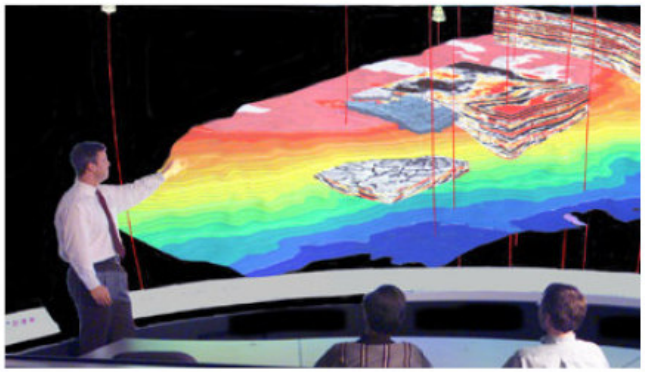
Mitchum et al., 1977b

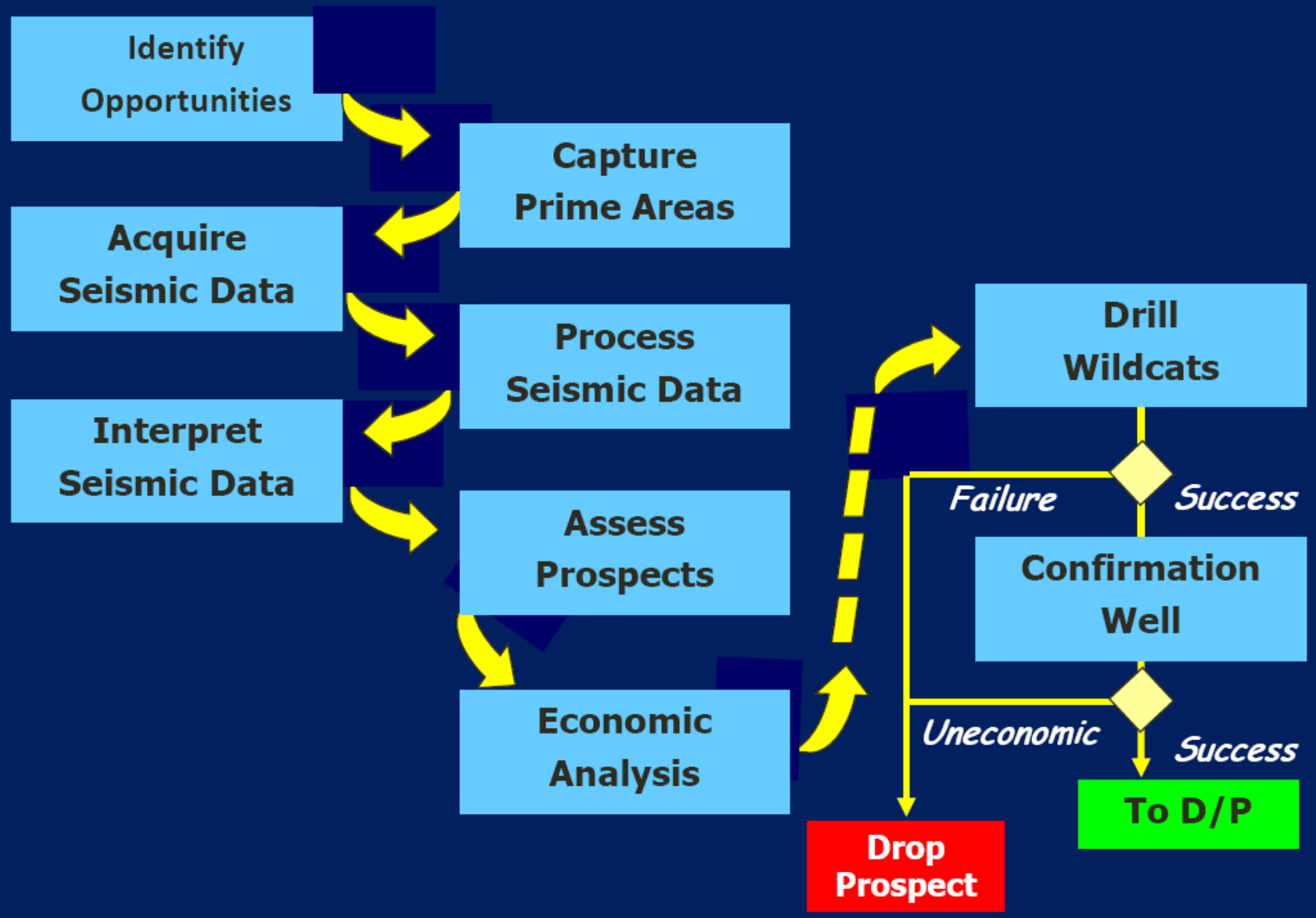




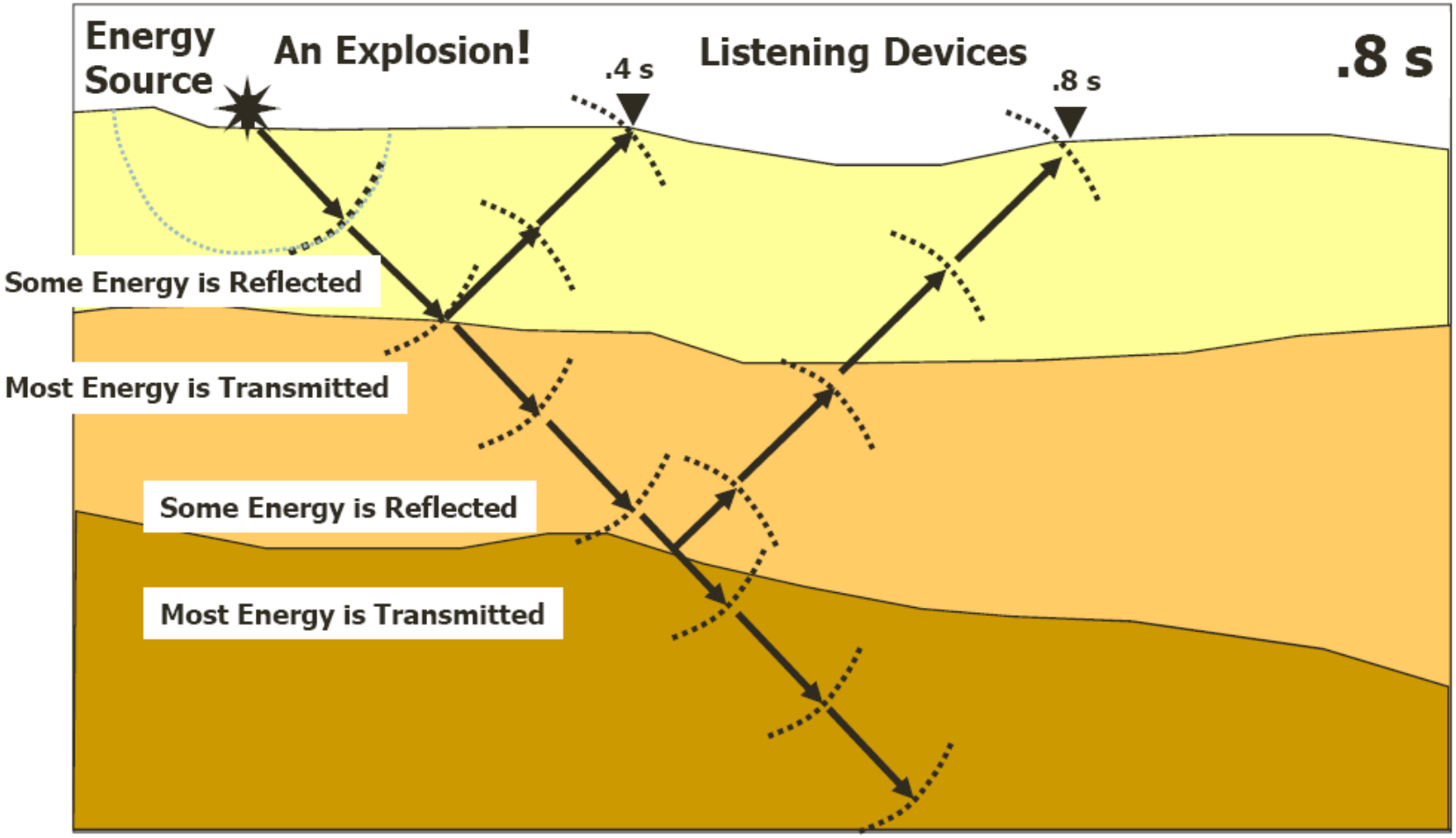


Courtesy of ExxonMobil

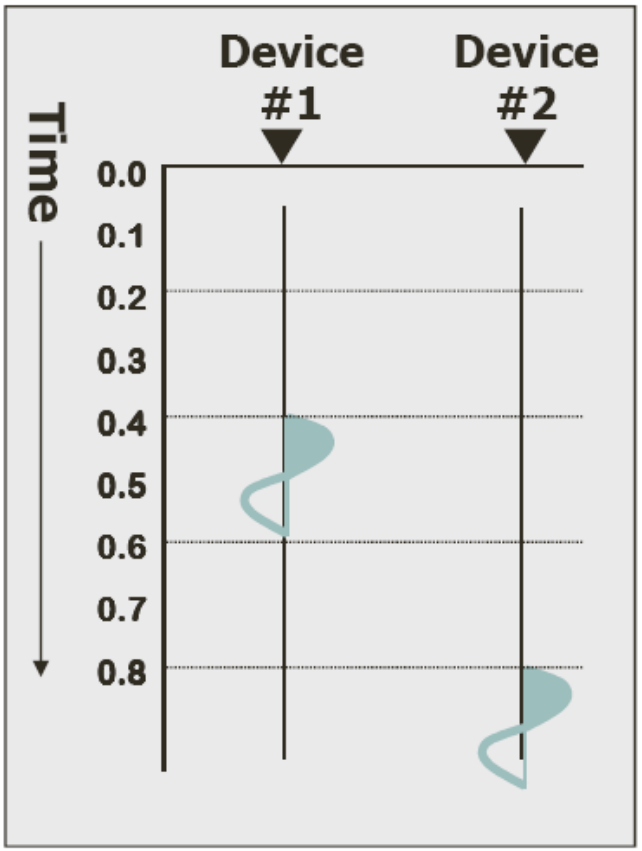
Basic Exploration Workflow



The Seismic Method



Raw Seismic Data



Listening device #1 records a reflection starting at 0.4 seconds

Listening device #2 records a reflection starting at 0.8 seconds

To Image the Subsurface, Use Many Shots (explosions) and Many Receivers (listening devices) Arranged in Lines either on Land or Offshore

Seismic Acquisition

- **A 3D survey is designed based on:**
  - **Imaging Objectives**: image area, target depth, dips, velocity, size/thickness of bodies to be imaged, etc.
  - **Survey Parameters**: survey area, fold, offsets, sampling, shooting direction, etc.
  - **Balance** between **Data Quality** & **$$$$$**

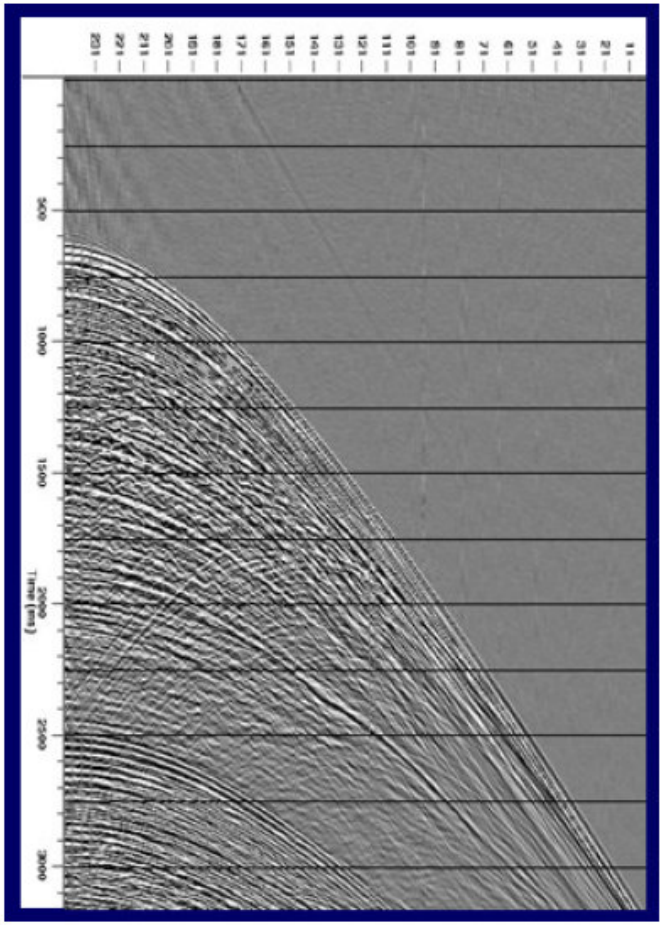
Land Operations

Vibrators Generate a Disturbance
Geophones Detect Motion

Marine Operations

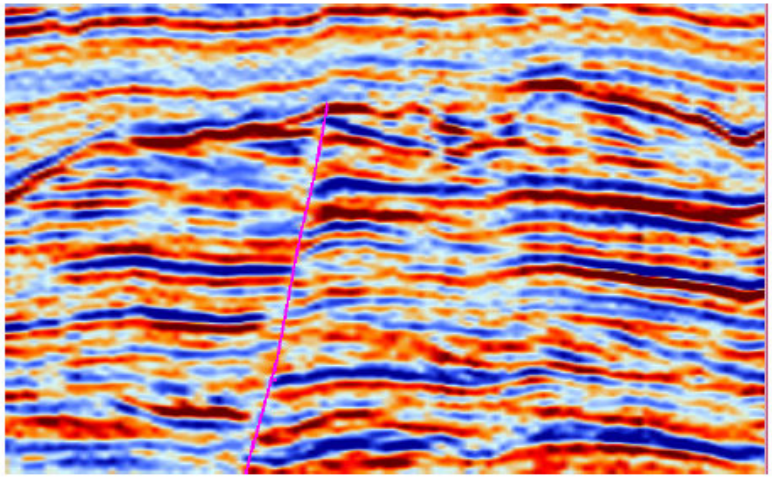
Air Guns Generate a Disturbance
Hydrophones Detect Pressure

Seismic Processing



Field Record
(marine)

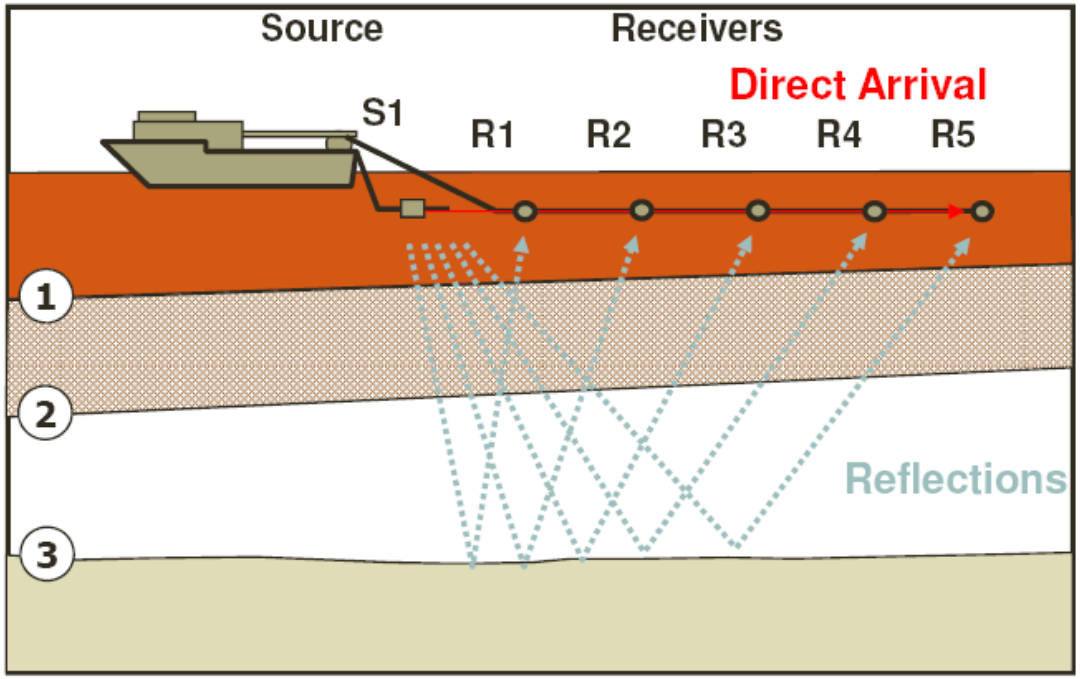
Data Processing Stream

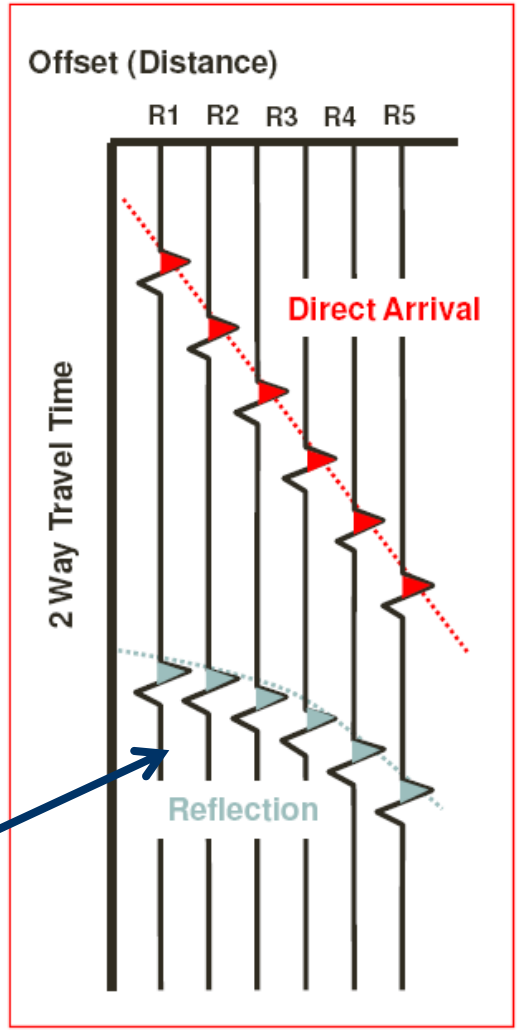


Subsurface 'Image'

Shot Gather

Travel times differ because the path for a near offset trace is less than the path for a far offset trace

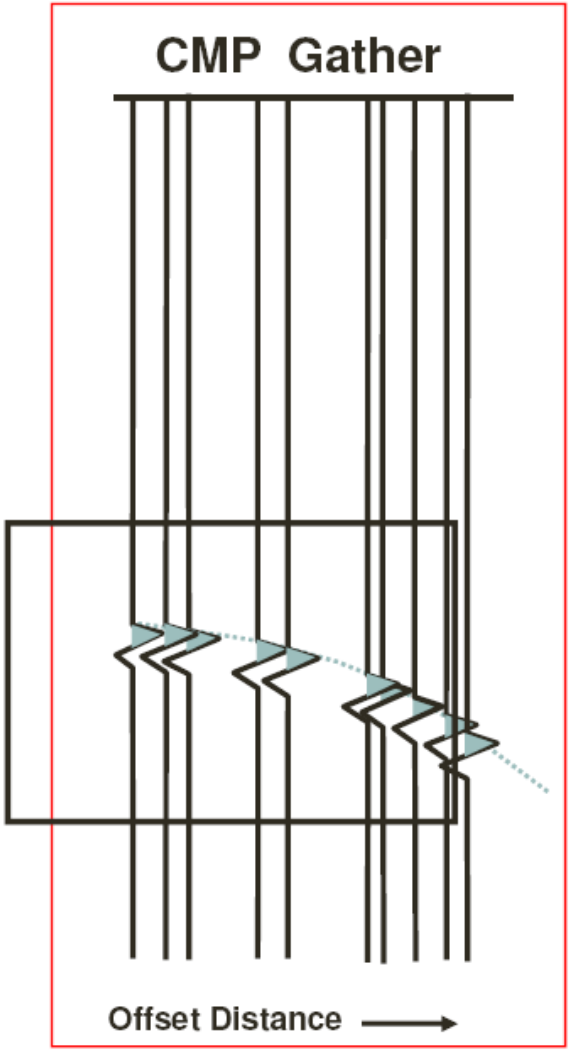


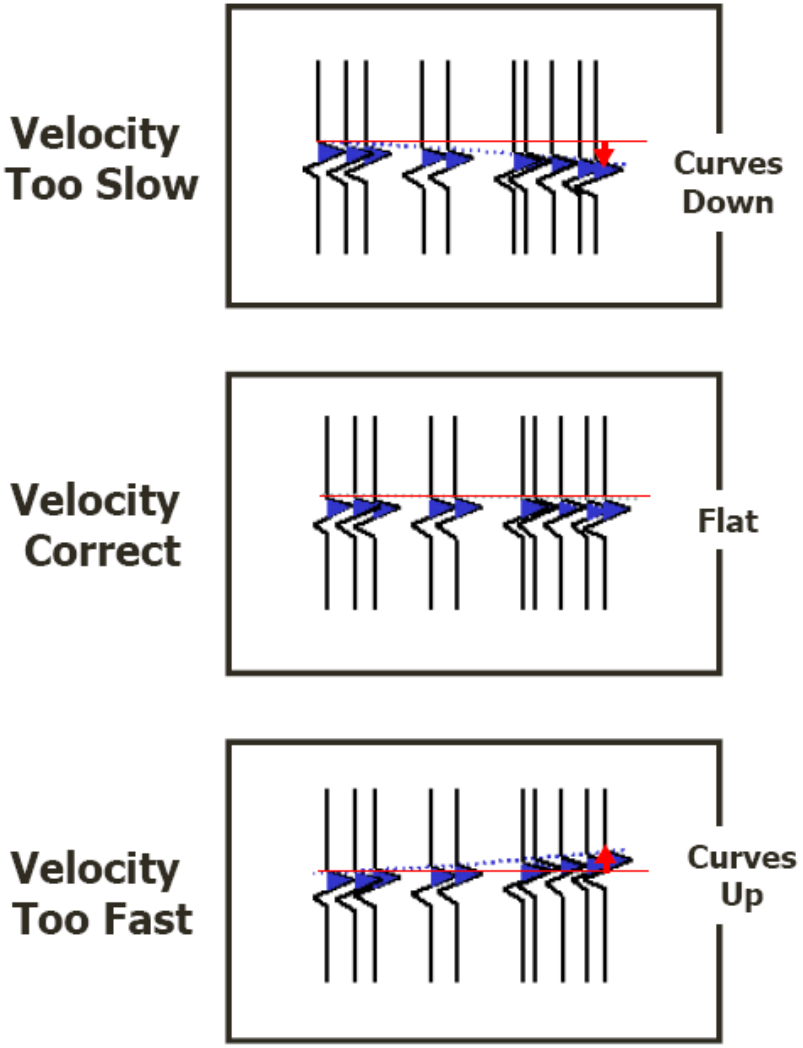


The difference in travel time for each trace can be corrected knowing the unit velocities.

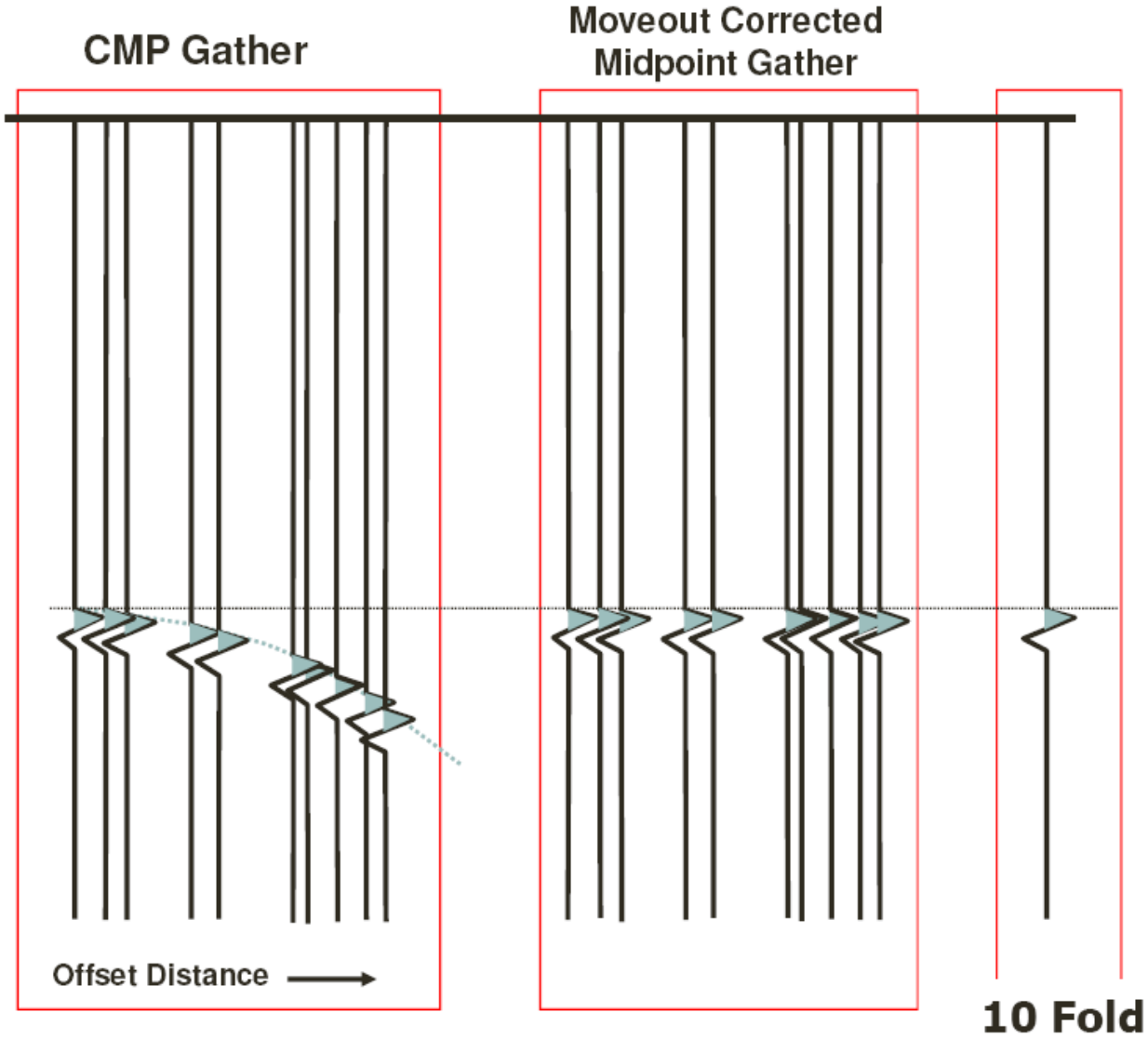
The curvature of the hyperbola is a function of the average velocity down to the depth of the reflection

With Correct Velocity, Gather is Flat





A Stacked Trace



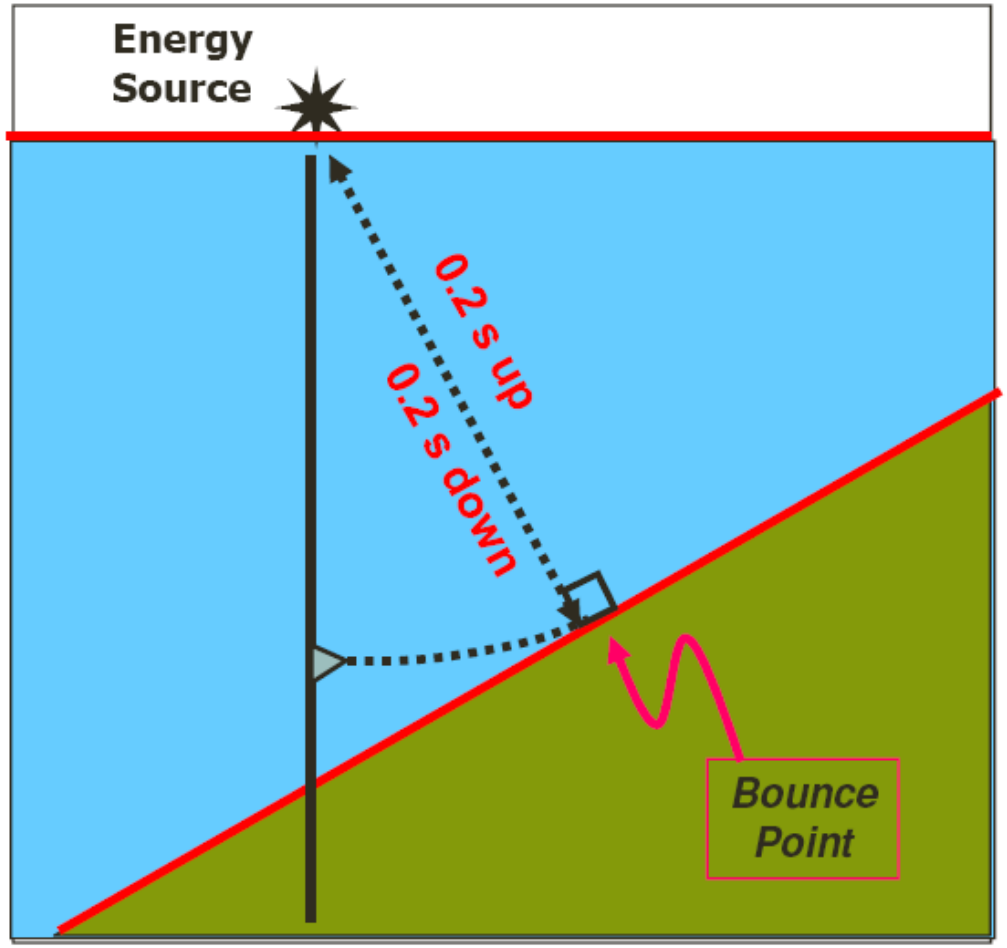
Stack several offset traces (# traces = fold)

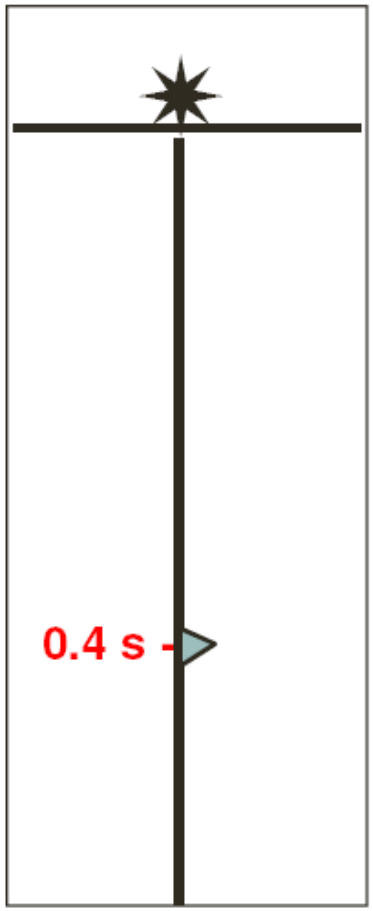
The geologic 'signal' will be additive

The random 'noise' will tend to cancel

Stacking greatly improves S/N (signal-to-noise)

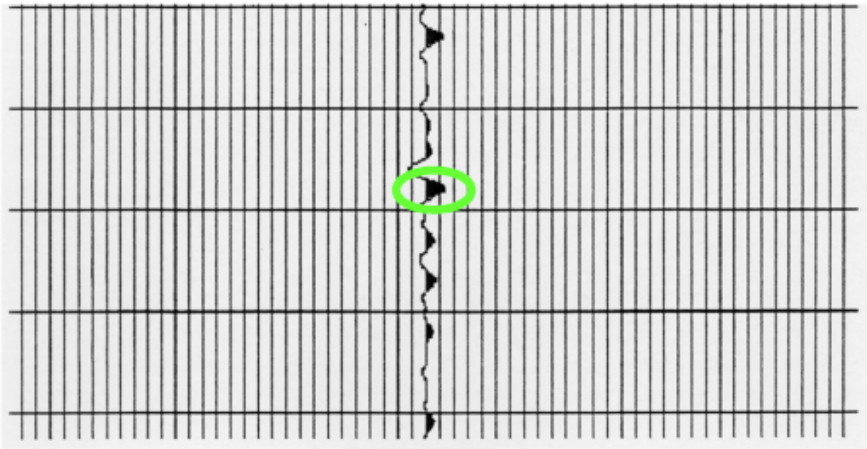
Positioning Problems

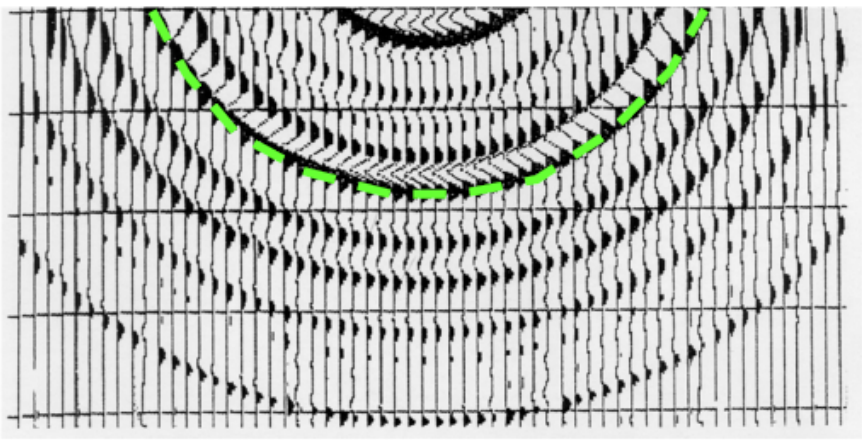


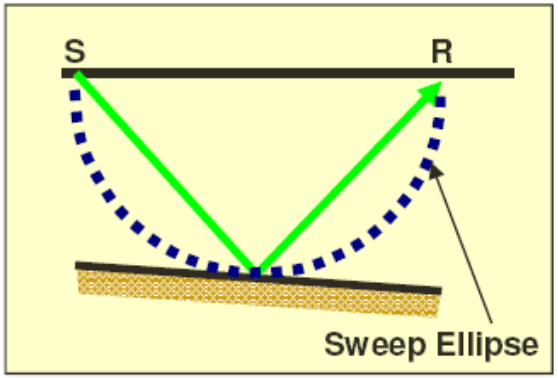


Migration – Correcting for Location

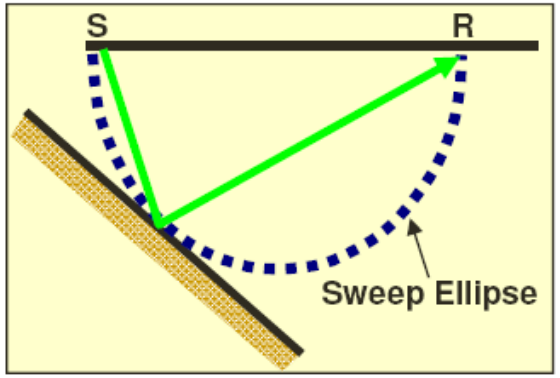
Unmigrated energy on single trace...







OR



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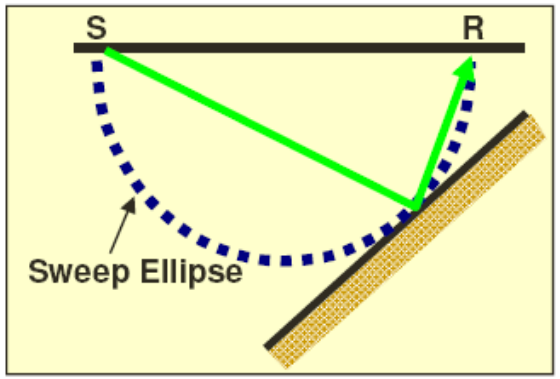
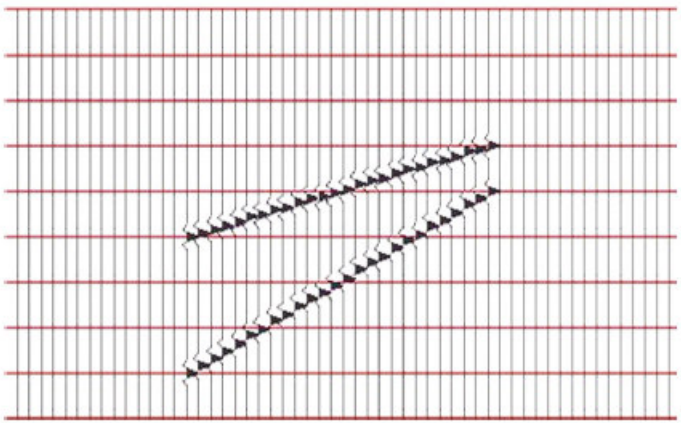


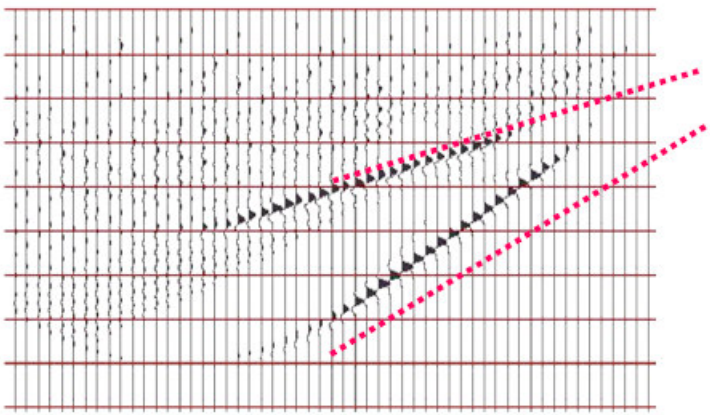
Migration – Power of Correlation

Two reflections on unmigrated data



Reflections are not positioned in the subsurface correctly since they have dip

After spreading to all possible locations

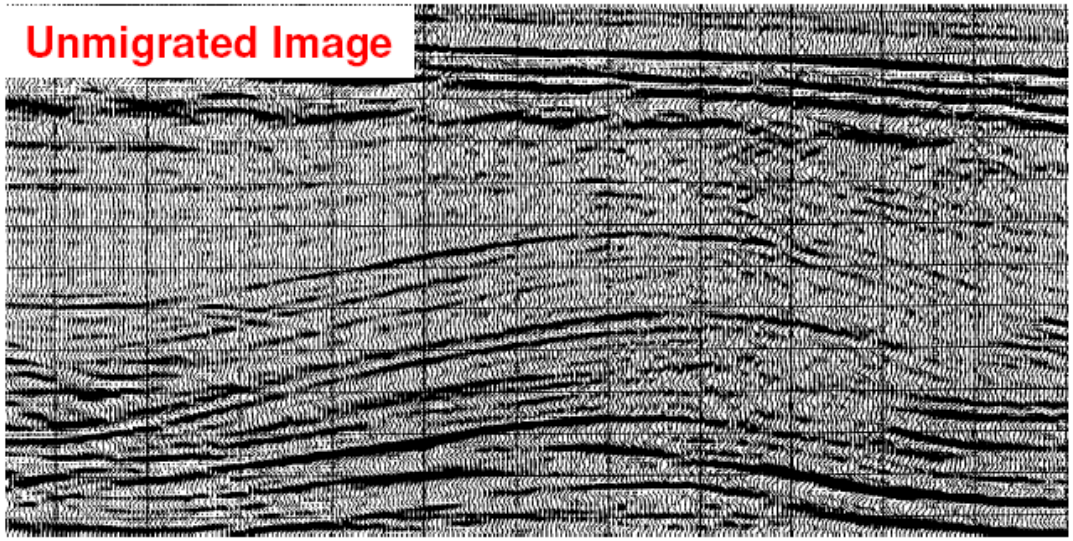


Constructive interference occurs where the reflections are properly positioned

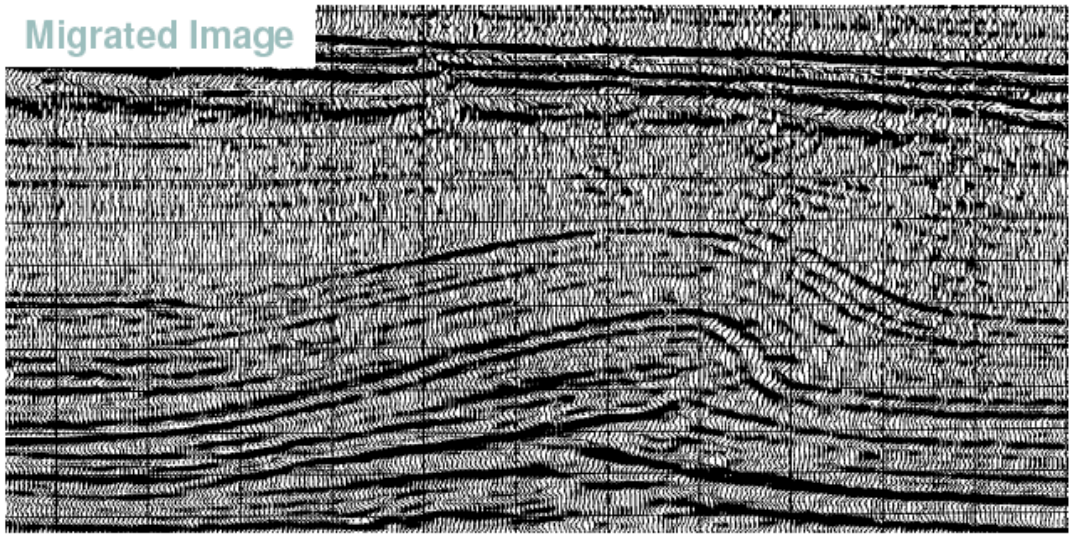
Destructive interference dominates where the reflections are NOT properly positioned

Seismic Migration

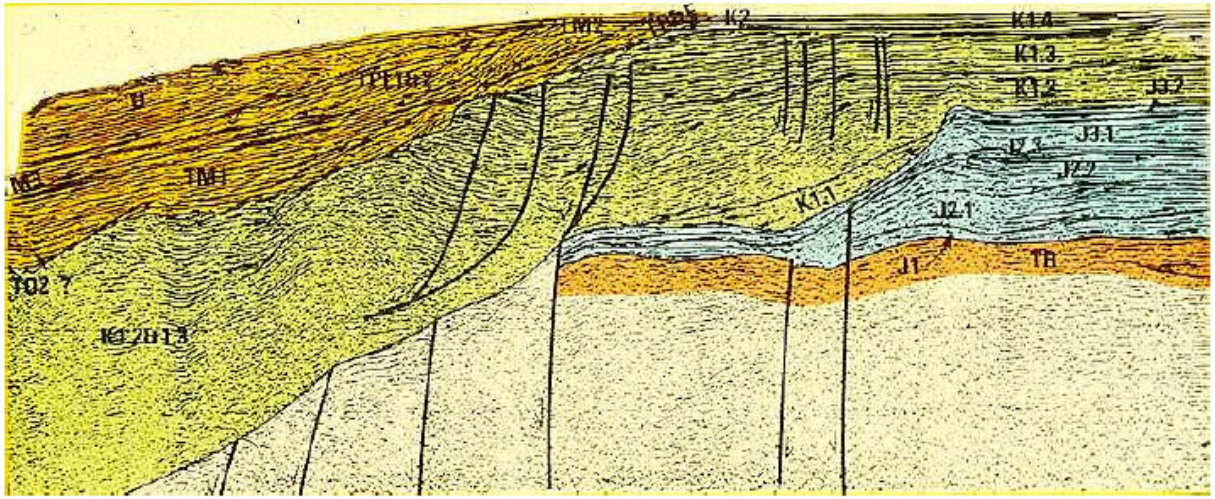
Positioning Problems 'Blur' the Image



Migration Reduces Positioning Problems, which Improves the Image



Seismic Interpretation



Determine the local geology from the subsurface images

- **Map faults and other structural features**
- **Map unconformities and other major stratal surfaces**
- **Interpret depositional environments**
- **Infer lithofacies from reflection patterns & velocities**
- **Predict ages of stratal units**
- **Examine elements of the HC systems**

Energy Resources

- **Fossil Fuels** - energy stored in chemical bonds of ancient organic life
  - Oil, Shale Oil & Oil Shale
  - Natural gas & Shale Gas
  - Tar sand
  - Coal
- Sun is ultimate energy source for photosynthesis of the plant organics

Oil and Natural Gas - Hydrocarbons

- **Petroleum:** complex compounds of Carbon (C) and Hydrogen (H) including oil and natural gas
- **Oil:** heavy liquid hydrocarbon compounds
- **Natural Gas:** mostly methane (CH_4)
- Mixture of hydrocarbons in most oil fields

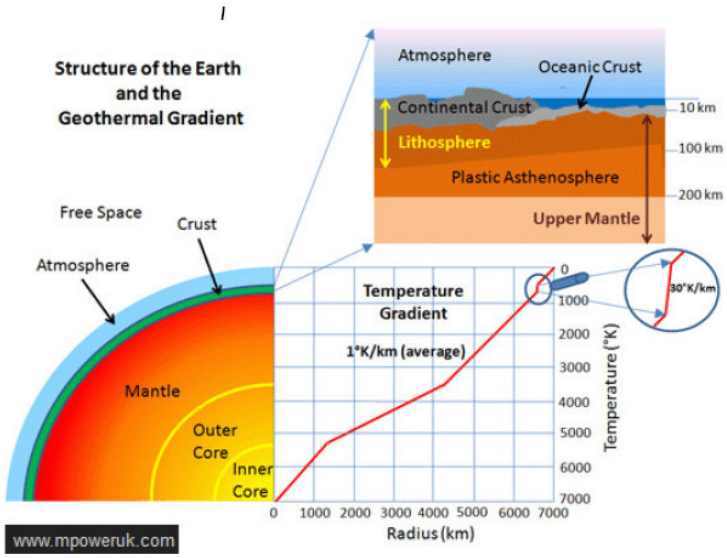
Formation of Oil and Gas Deposits Source & Burial

- Marine microorganism source - Organisms die and remains settle to the sea floor
- Source Rock is rich in carbon and hydrogen, accumulates and rapidly buried –
- Some natural gases & coal are from similar burial of massive amount of land plant material

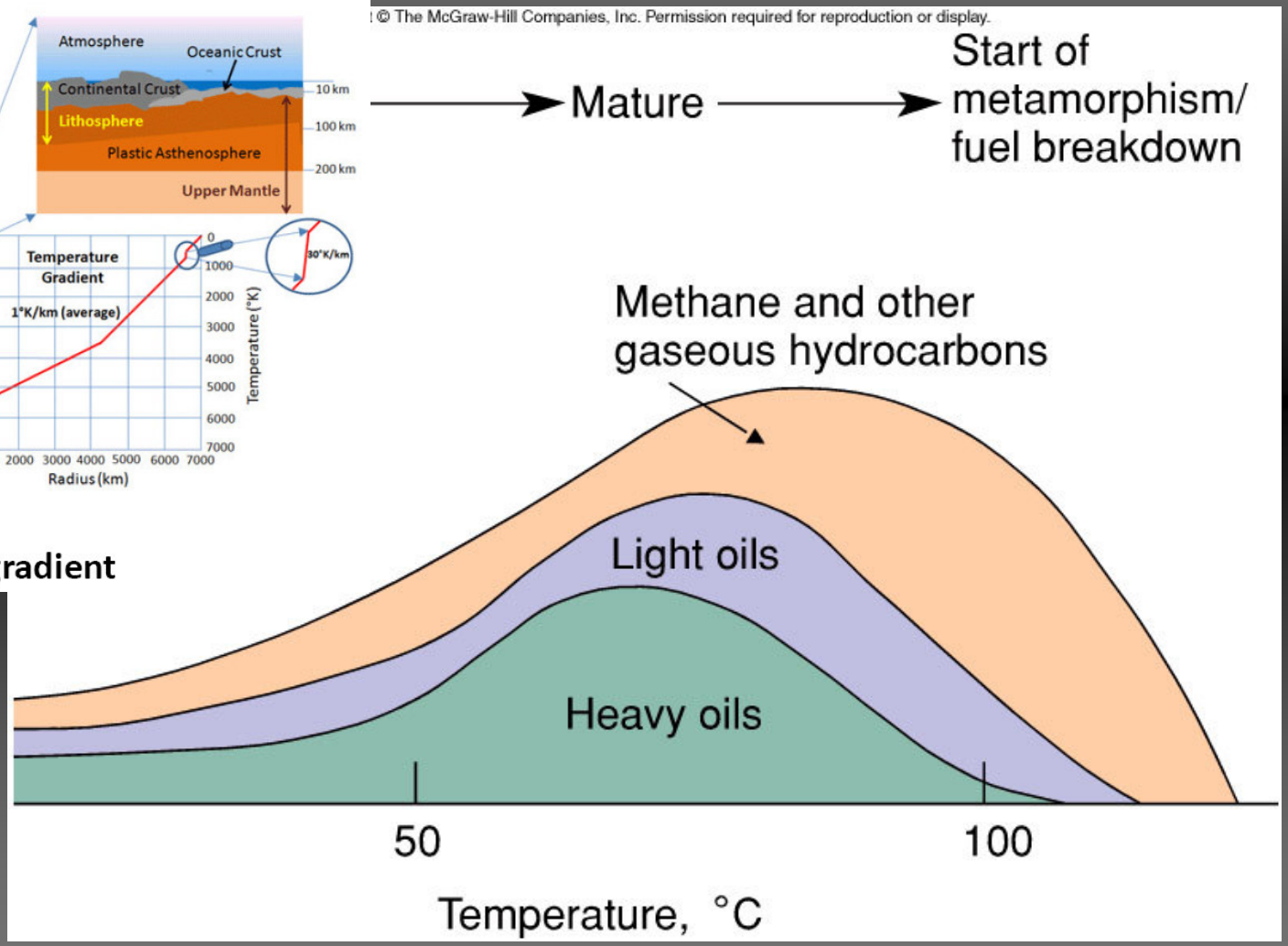
Petroleum Maturation

1) HEAT

Near surface: **25 °C per km of depth** in most of the world (1 °F per 70 ft)



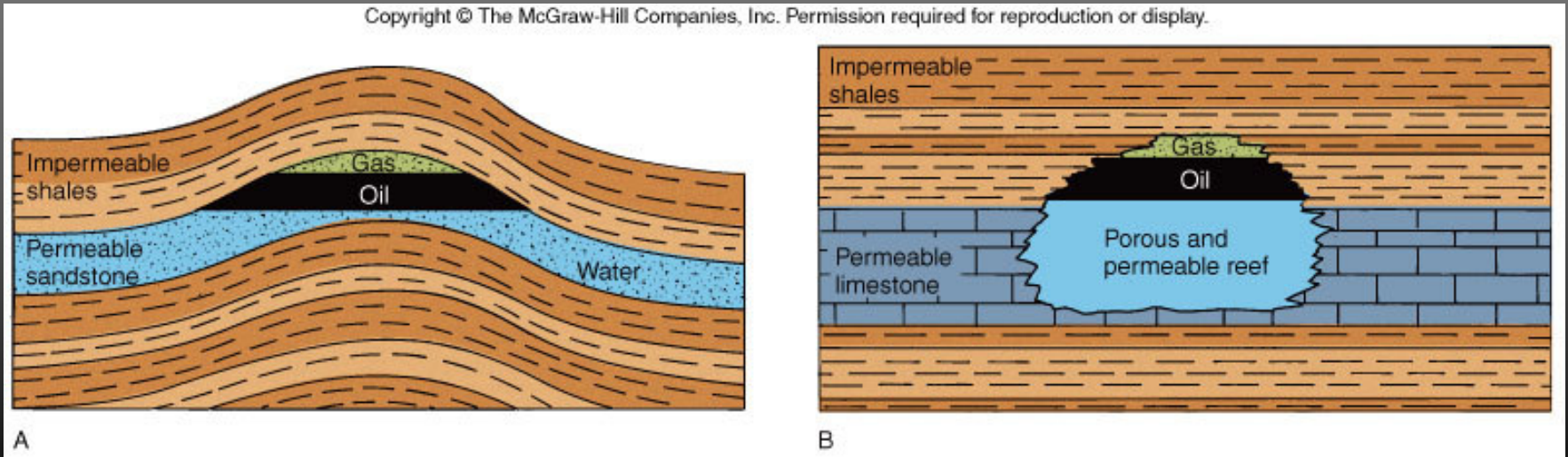
Geothermal gradient



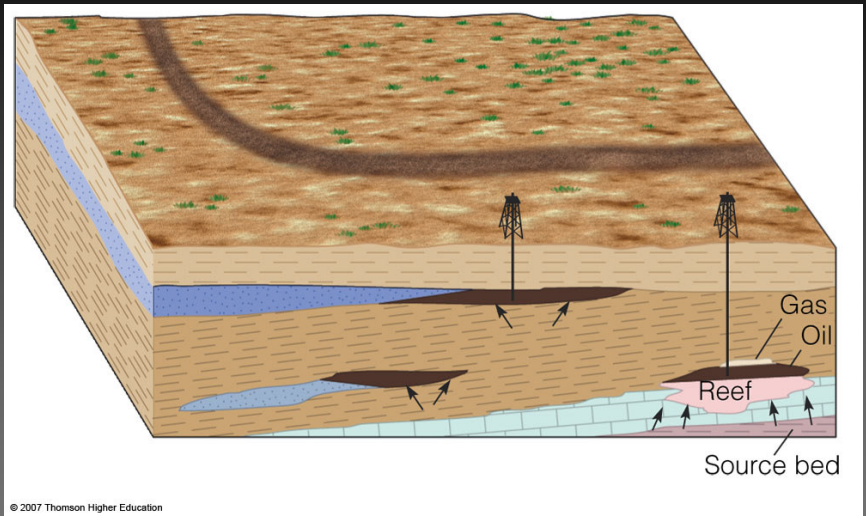
Oil and Gas Migration

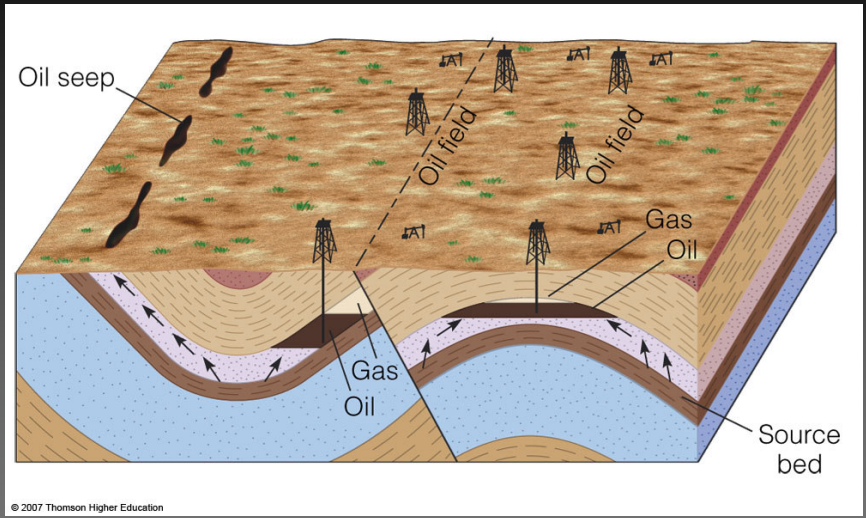
- Liquid and gaseous hydrocarbon migrate out of sedimentary rocks in which formed
- Migrate into permeable reservoir rocks - hydrocarbons pool in economic deposits
- Petroleum Reservoirs or Traps - permeable rocks (sandstone) overlain by impermeable trap rocks (shale)

Petroleum Reservoirs or Traps

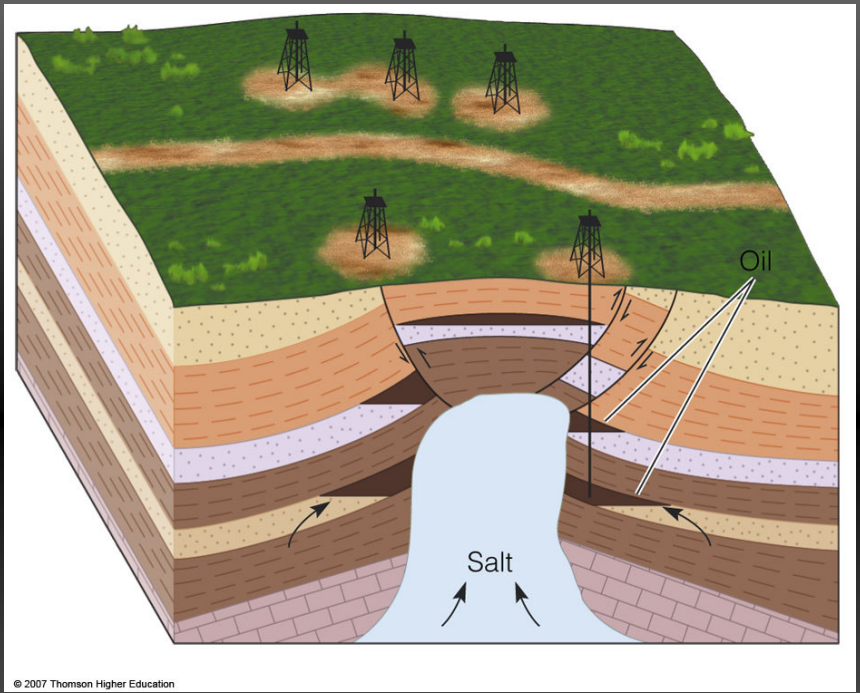


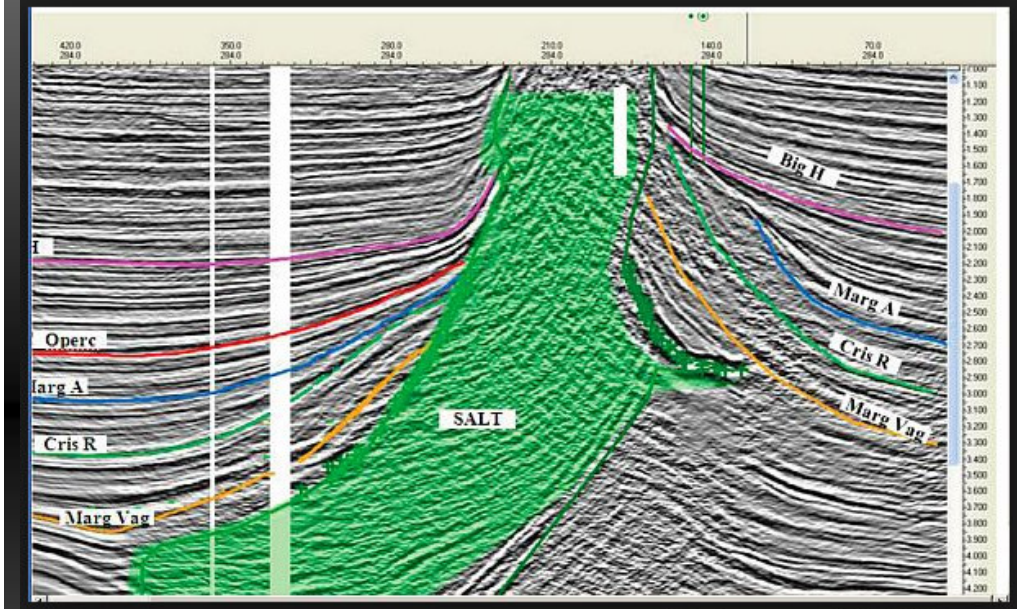
Unconformity, Reef & Discontinuous Unit, Fold & Fault Traps





Salt Dome Traps





Louisiana: Assumption Parish Bayou… flutrackers.com - 600 × 364

Time

- Most hydrocarbon deposits found in rocks 1 to 2 million years old

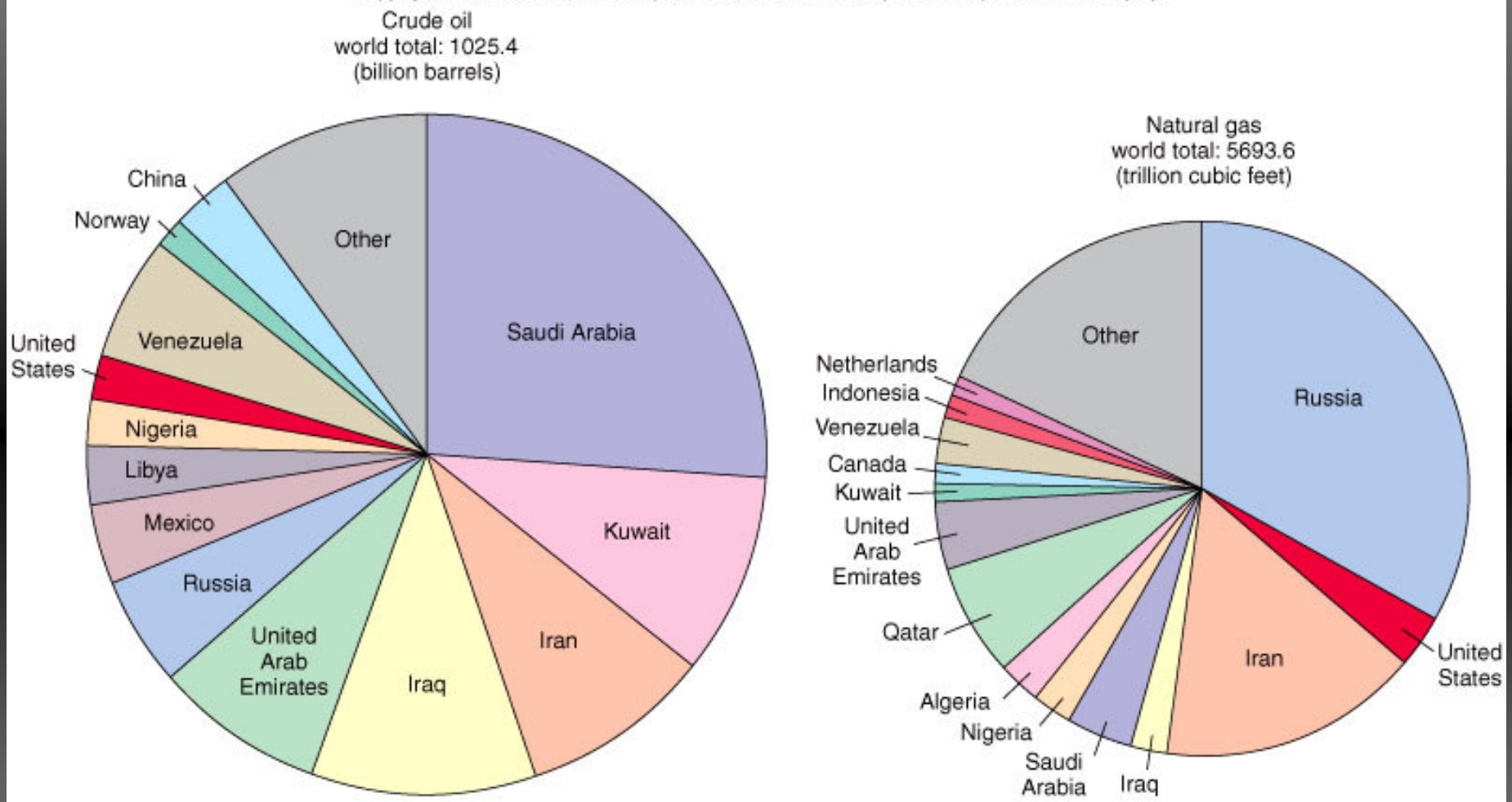
- Process is slow and takes longer than a few tens of thousands of years

- Oil and Natural gas are **nonrenewable** energy resource – i.e. organic material falling to the sea floors today will not be useful petroleum products many lifetime

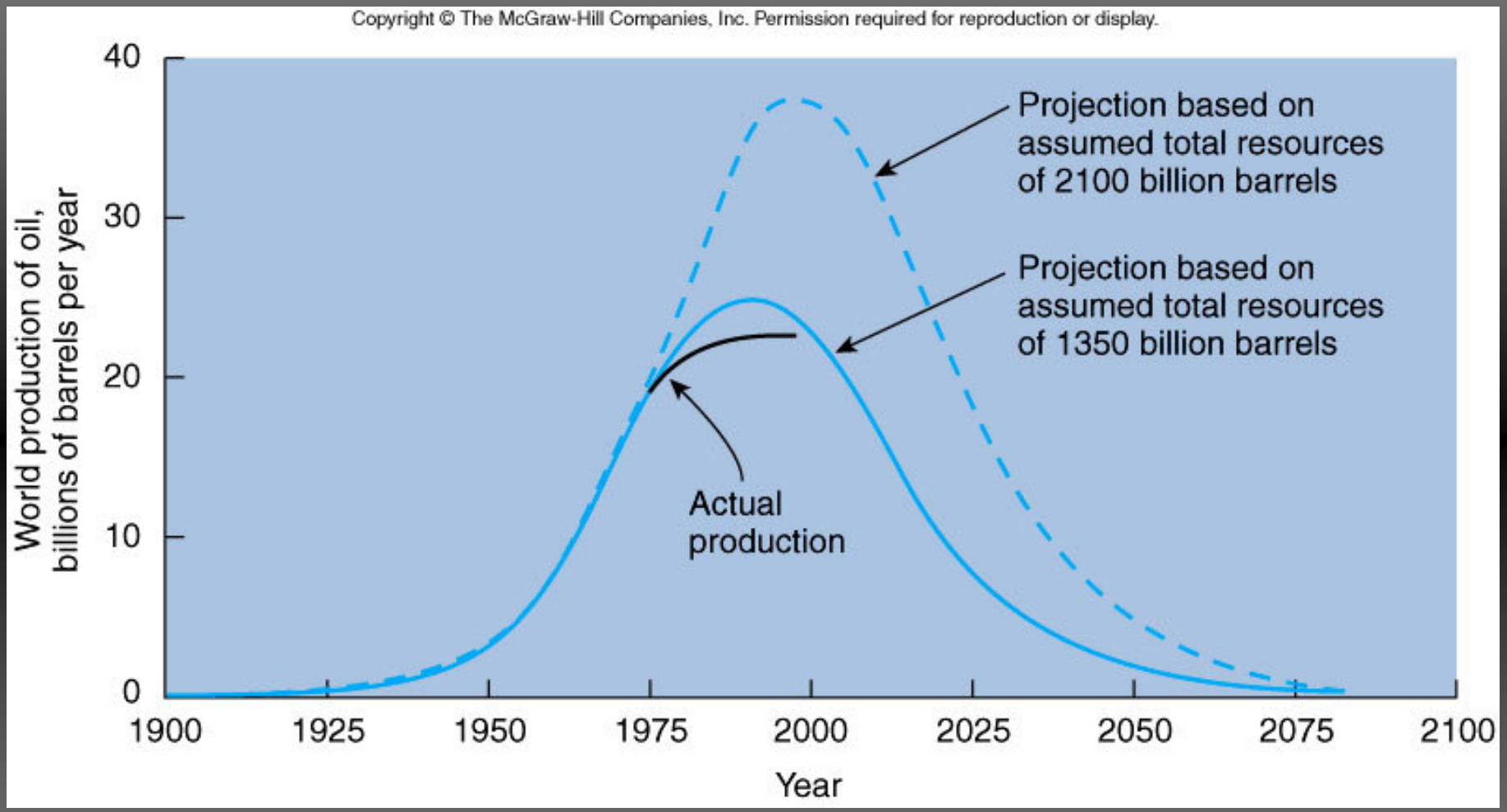
World and US Oil Supply and Demand

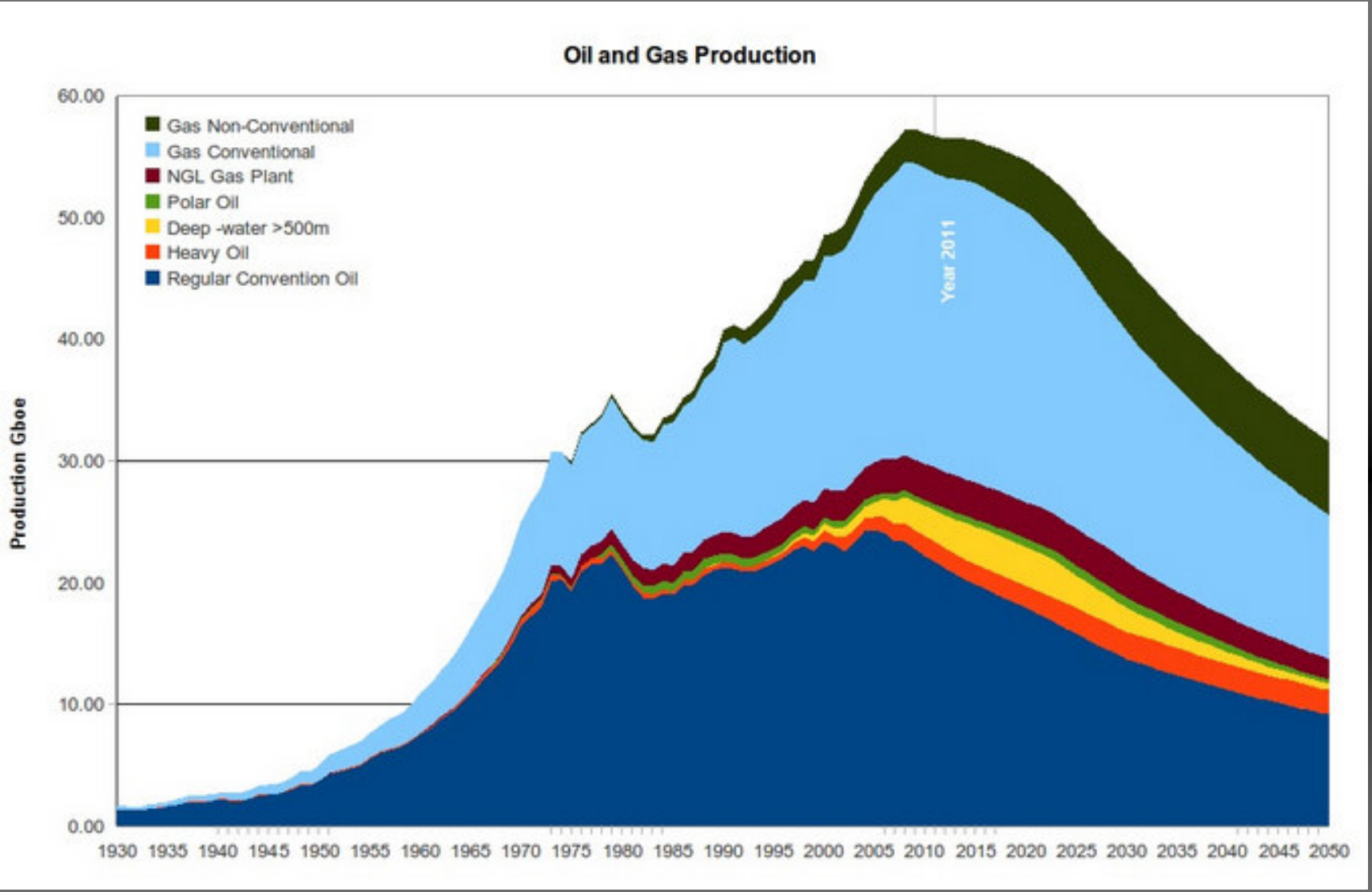
- Proven reserves in 2002 at 1 trillion barrels (1 barrel = 42 gallons)
  - Unevenly distributed around the world
  - Most oil consumed by industrialized countries
- Worldwide ~500 billion barrels of oil have been consumed (half in the last 25 yrs)
- 200 billion barrels of oil have been produced and consumed in the U.S. (~ 7 billion barrels of oil per year)
- U.S. had 23 billion barrels of reserves 2002
  - U.S. production has recently increased – 10x
  - New shale oil fields being developed

Proven Oil & Gas Reserves (2002)

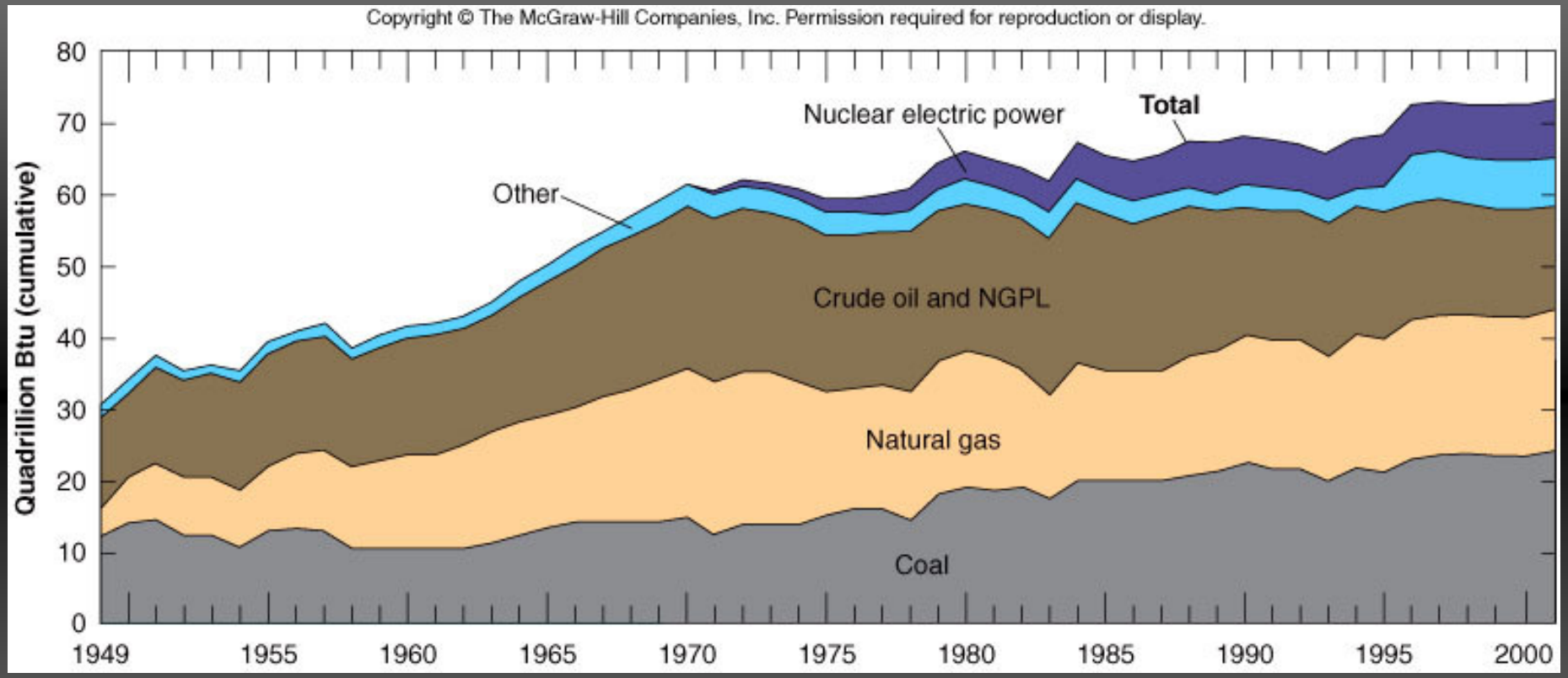


Peak Oil Projections - M. King Hubbert (1971)




Oil and Gas Production
Production Gboe
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Gas Non-Conventional
Gas Conventional
NGL Gas Plant
Polar Oil
Deep -water >500m
Heavy Oil
Regular Convention Oil
Year 2011
1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050

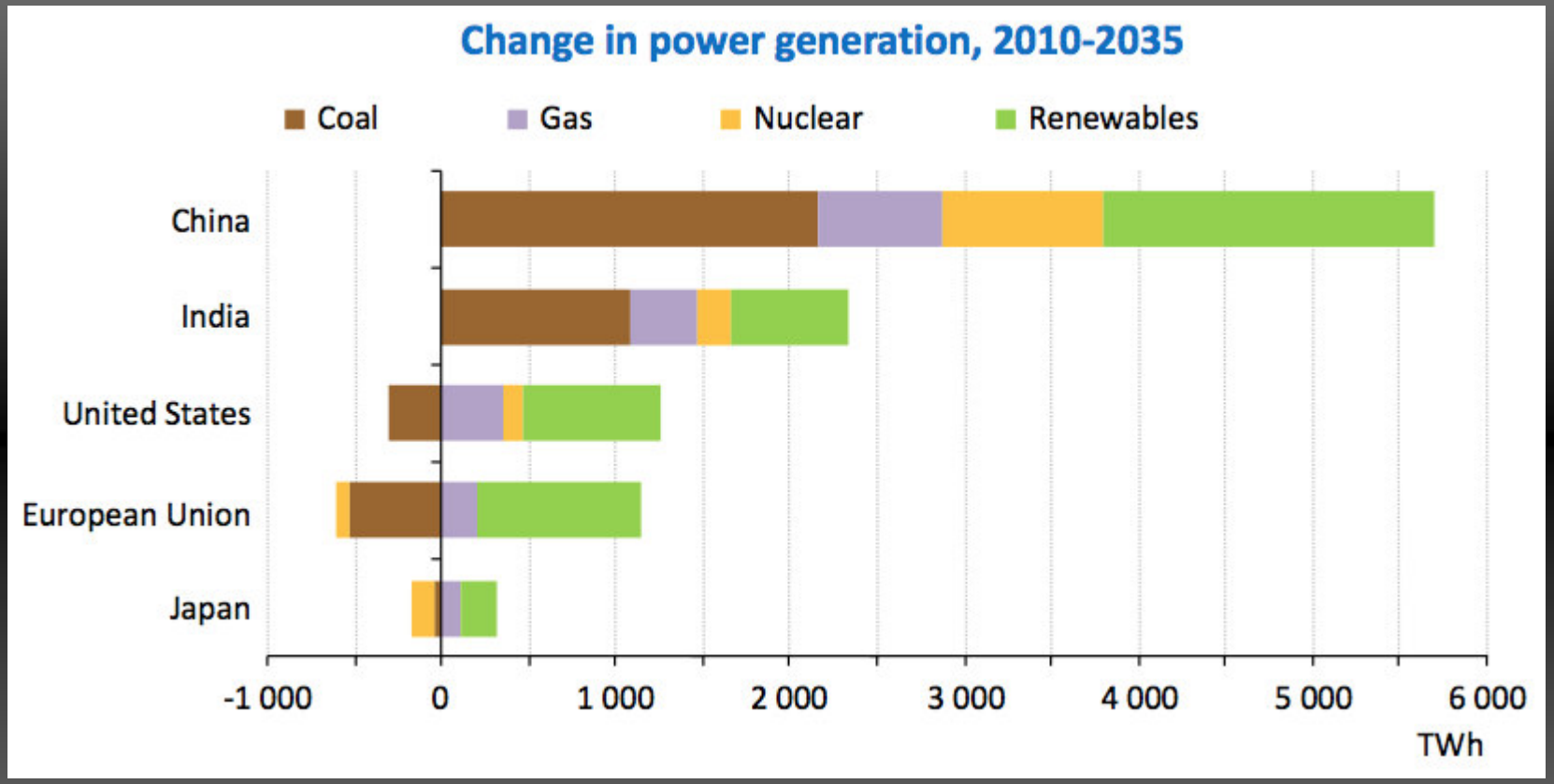
US Energy Production



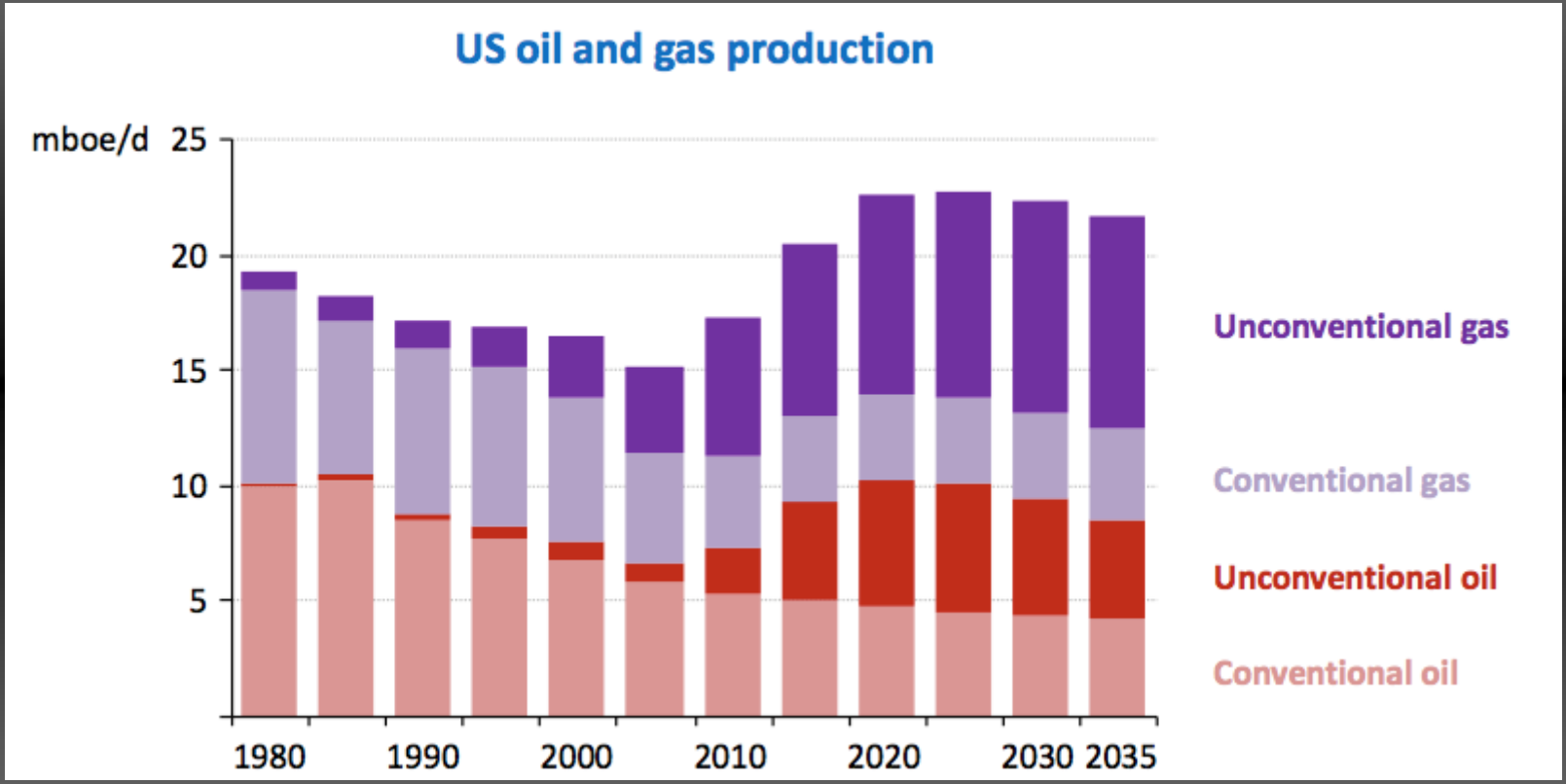
Major industry shifts taking place

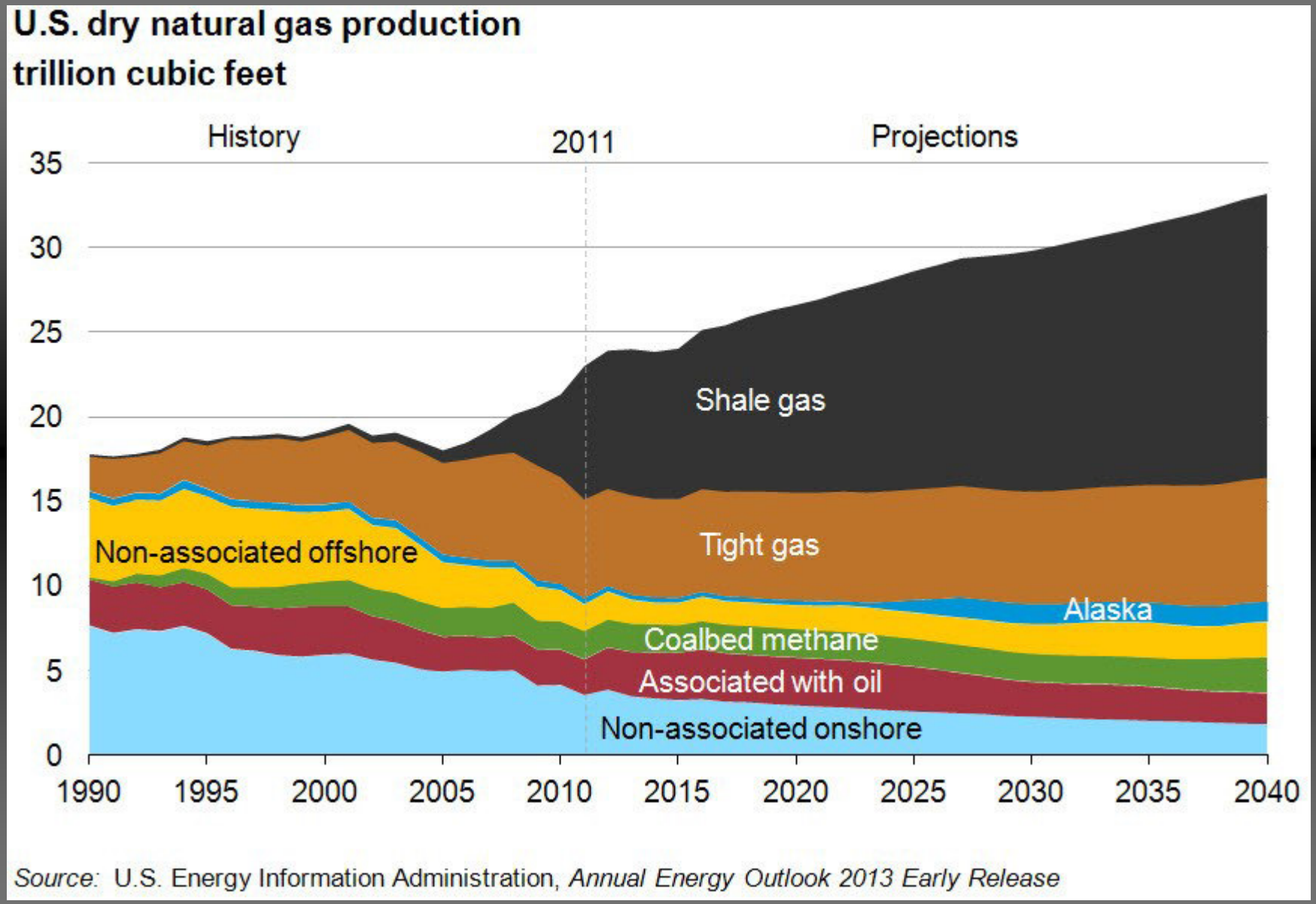
- U.S. energy shifting away from coal to natural gas
- New areas discovered – TX, PA & ND
  - New oil & gas resources (unconventional)
- **New technologies - horizontal drilling & hydraulic fracturing –** unlock oil & gas from impermeable shale source rock.
- **Primary recovery** – original pumping of oil under its own pressure
- **Secondary recovery** – pump water into reservoir to fill in empty pores and buoy up more oil to be pumped from the well
- **Tertiary recovery** – Use catalysts and heat to mobilize heavy components

World Energy Changes



Important Changes US Energy




U.S. dry natural gas production
trillion cubic feet
History
2011
Projections
35
30
25
20
15
10
5
0
Shale gas
Tight gas
Non-associated offshore
Alaska
Coalbed methane
Associated with oil
Non-associated onshore
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
Source: U.S. Energy Information Administration, Annual Energy Outlook 2013 Early Release

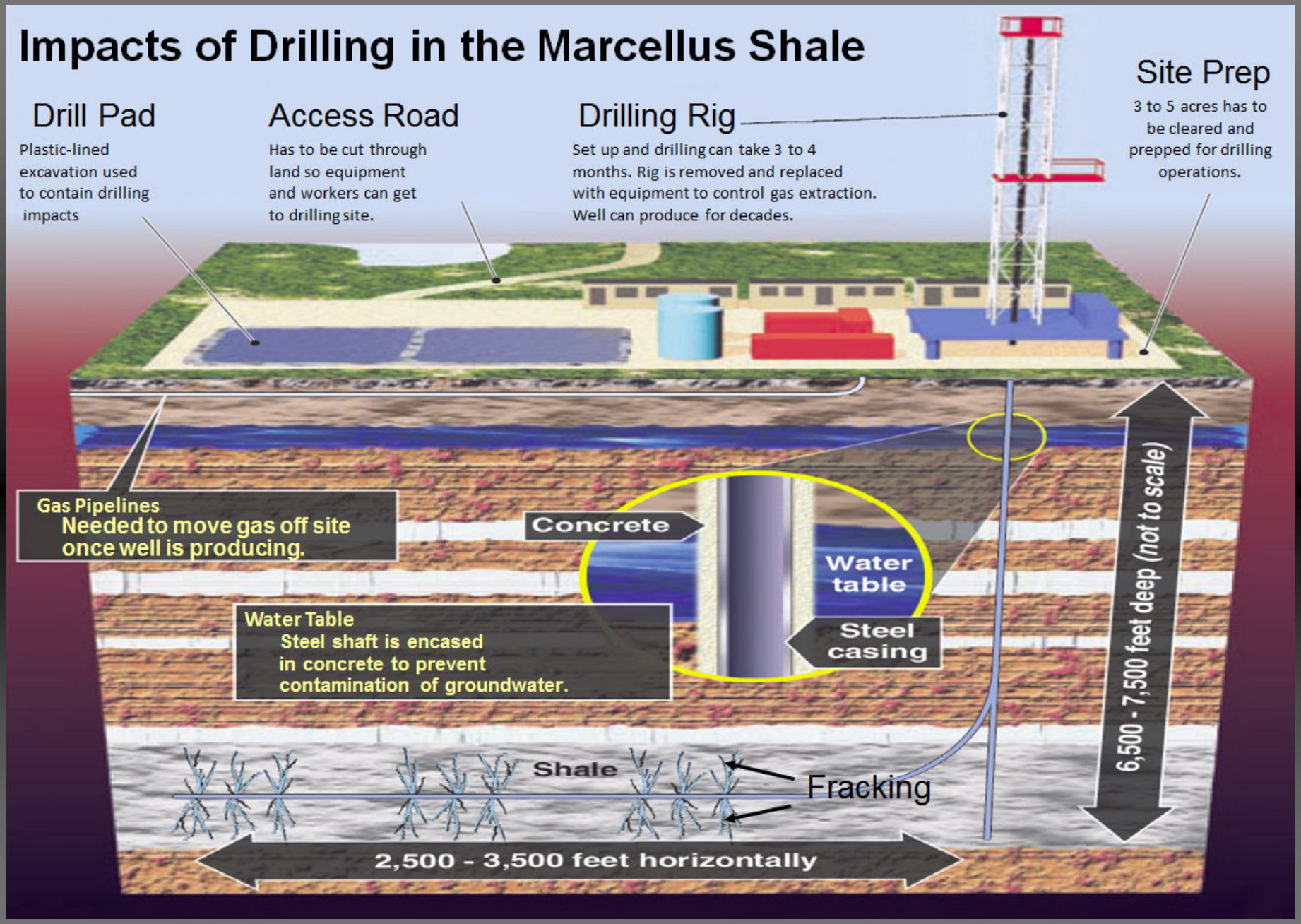
New Shale Gas Resources and Demands

- Natural gas trapped in Shale at depths of > 3000’
- Horizontal drilling & hydraulic fracturing (fracking)
  Estimated trillions of cubic feet but many environmental Concerns
- 25 % of energy used in U.S. is natural gas
  About 20 trillion cubic feet/yr consumed but >200 trillion cubic feet of proven reserves
- U.S. imports 15% of gas from Canada

Hydraulic Fracturing or ‘Fracking’

- US experiencing an energy/economic rebirth (worlds largest oil producer by 2020; gas displaces oil as largest component in energy mix by 2030)
- Regional importance to economic growth and cleaner domestic energy resource.
- New State (PA & NY) regulations to protect water resources
- Environmental concerns including induced earthquakes, introduction of ‘fracking fluids’ or chemicals and propping agents into the subsurface to enhance production

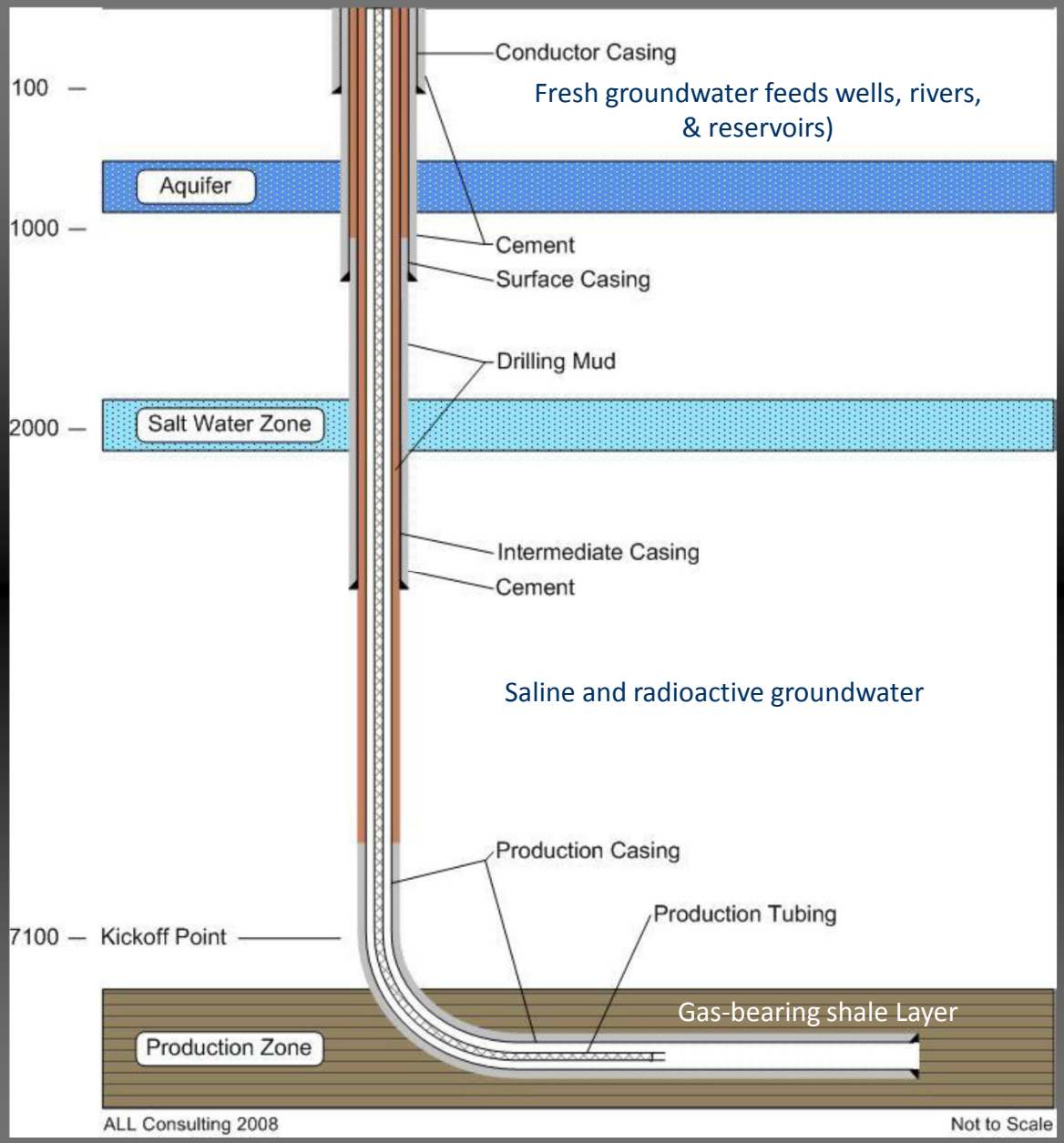
Impacts of Drilling in the Marcellus Shale



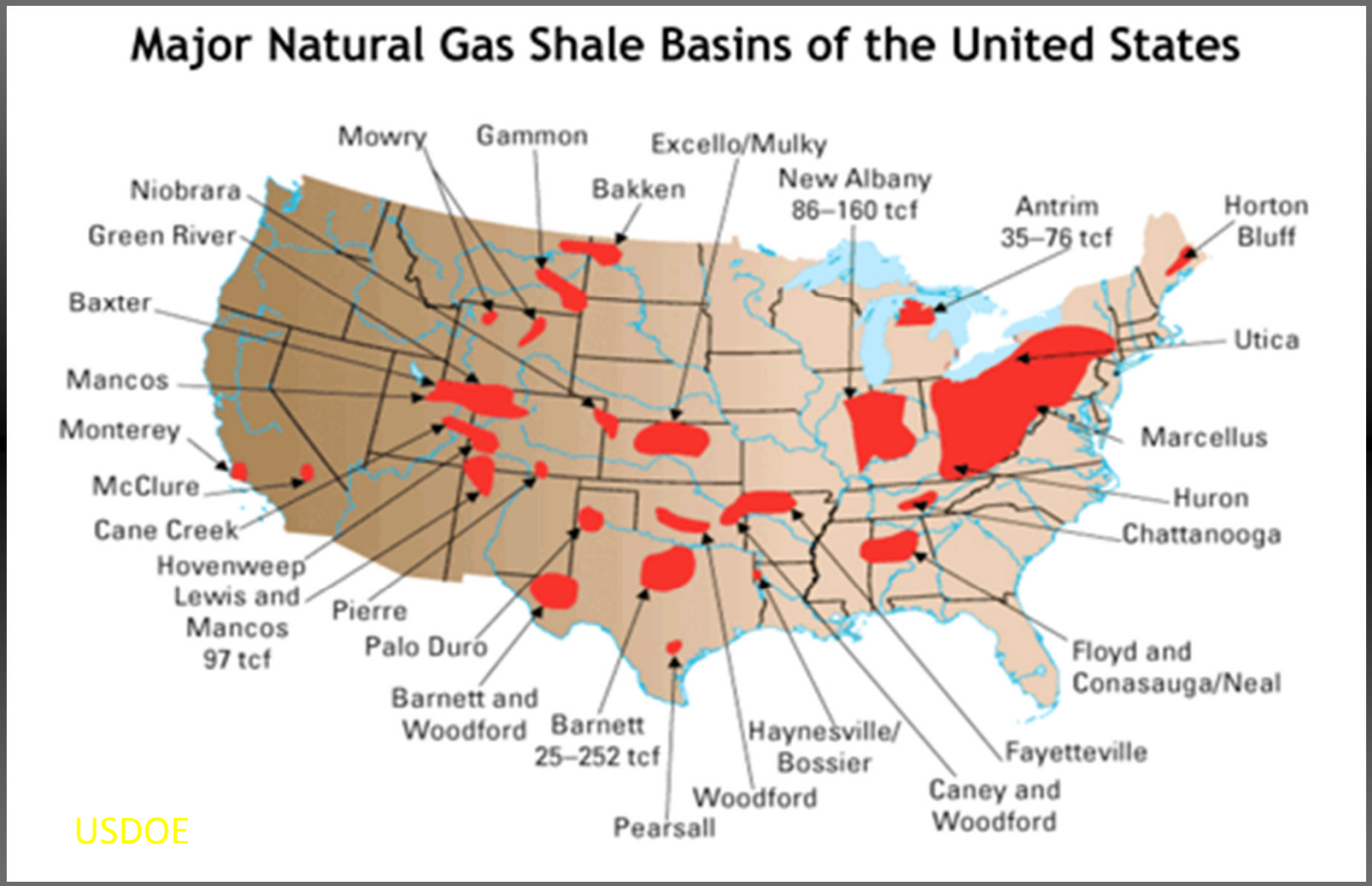
- Important to design wells with multiple casing & cement barriers

  Protect drinking water & isolate gas zones, thereby preventing problems that we have experienced

Drilled Hole

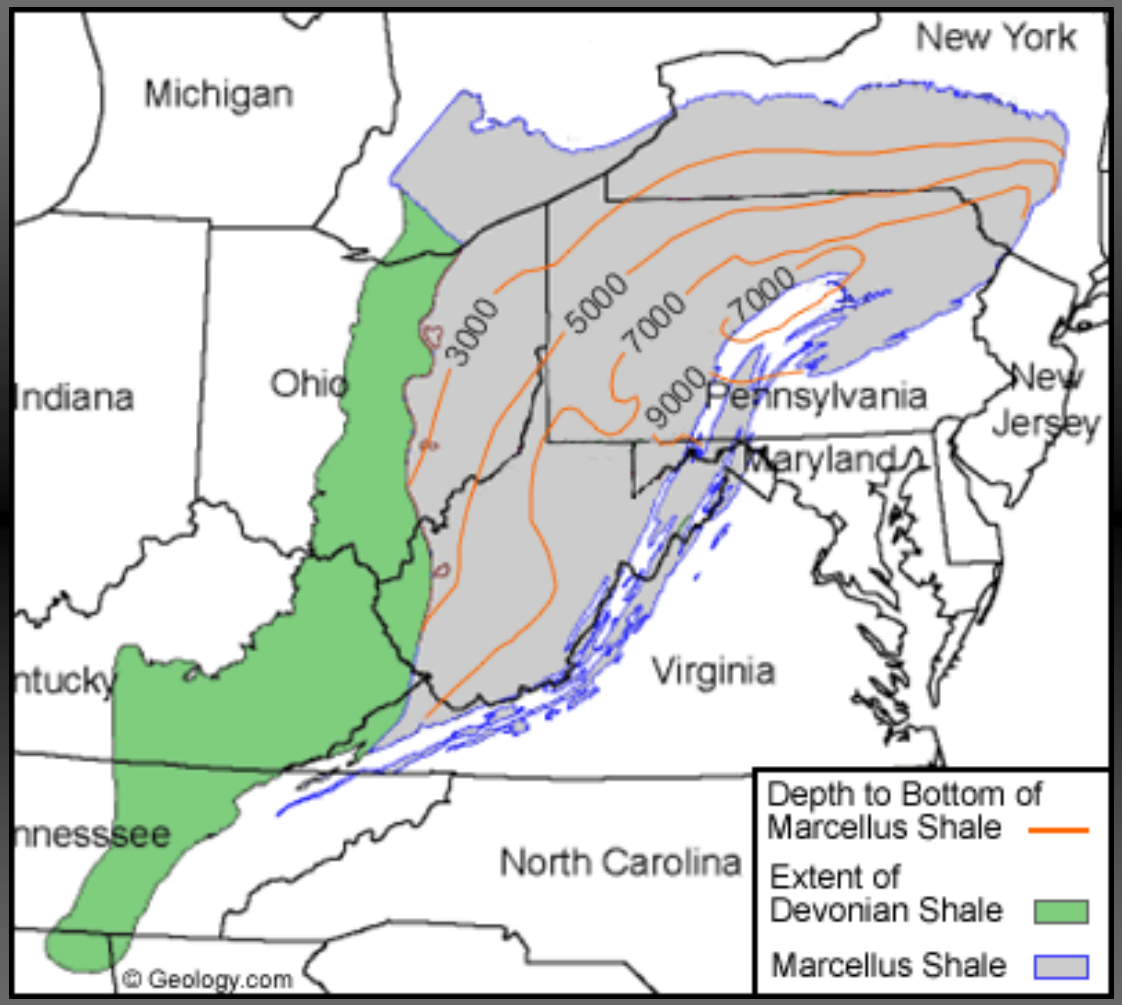


Changing Energy Resources

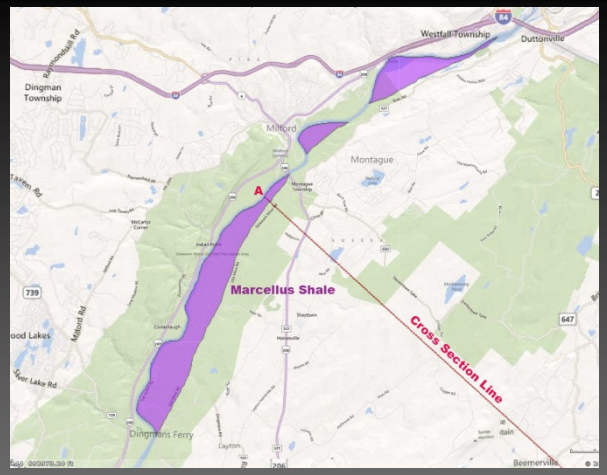


(Marcellus, Utica, Bakken, Eagle Ford, Lockatong?)

MARCELLUS SHALE (PA, NY, OH, WV)

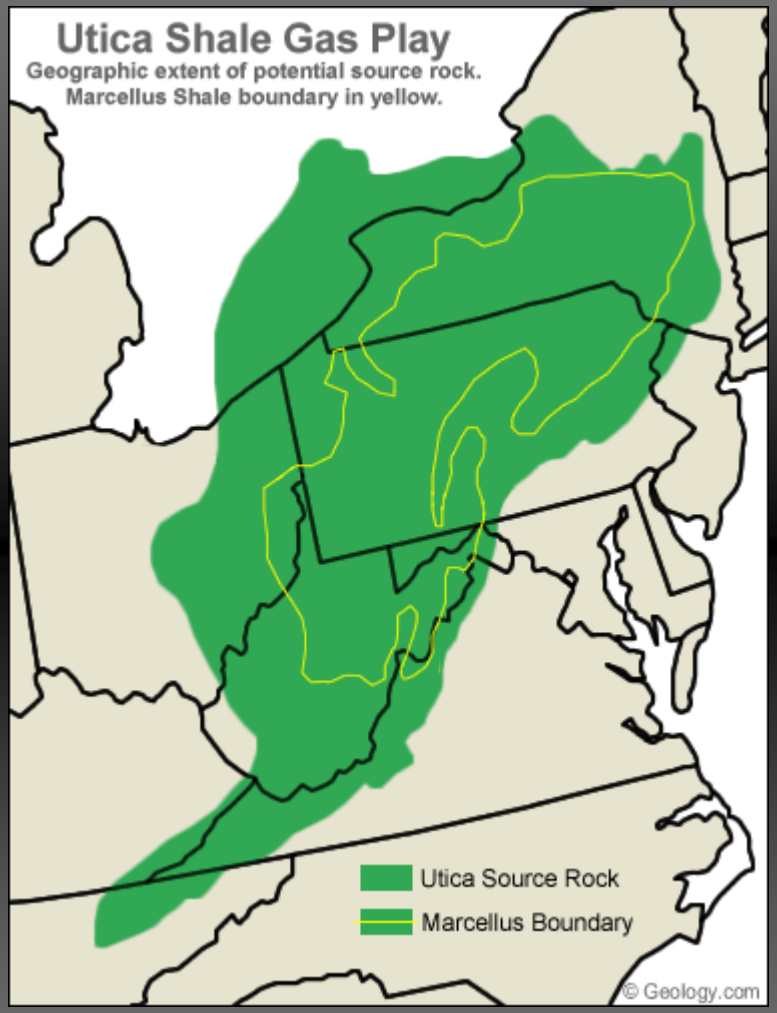


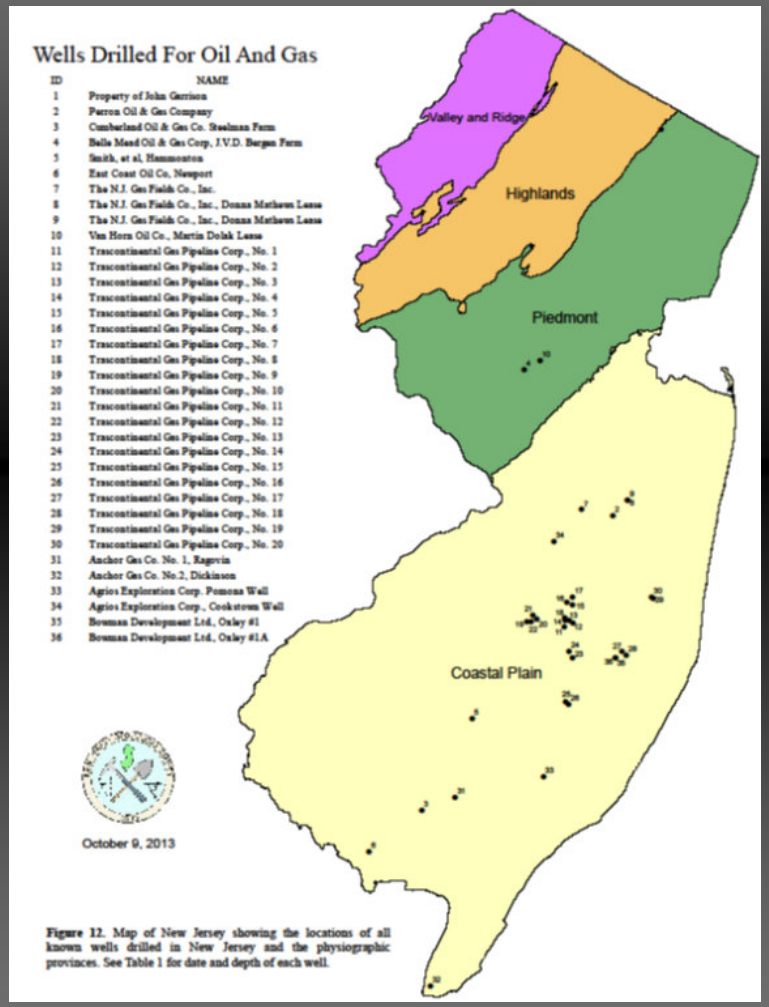
Too shallow in NJ



UTICA SHALE (PA, NY, OH, WV)

Overmature In NJ , i.e. the gas is driven off.

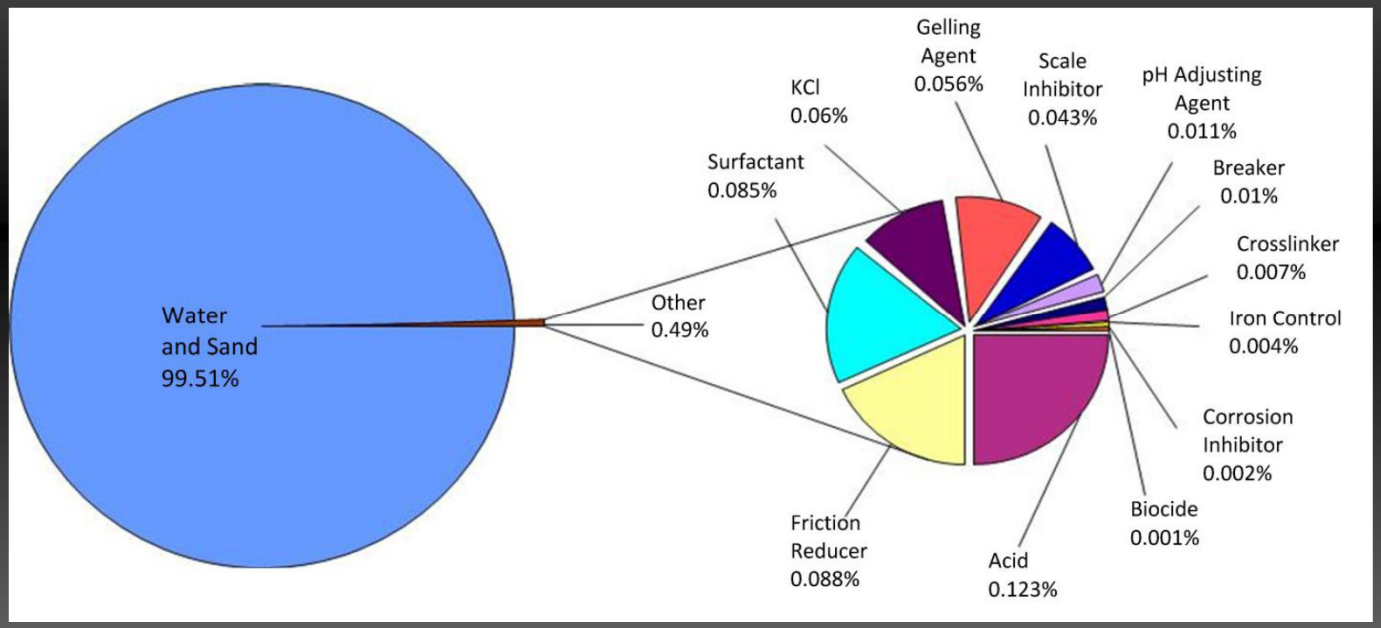




MARTINSBURG SHALE in NJ

Fluids used in Hydraulic Fracturing

- Minimize disposal
- Maximize reuse
- Substitute benign chemicals
- Public disclosures of composition



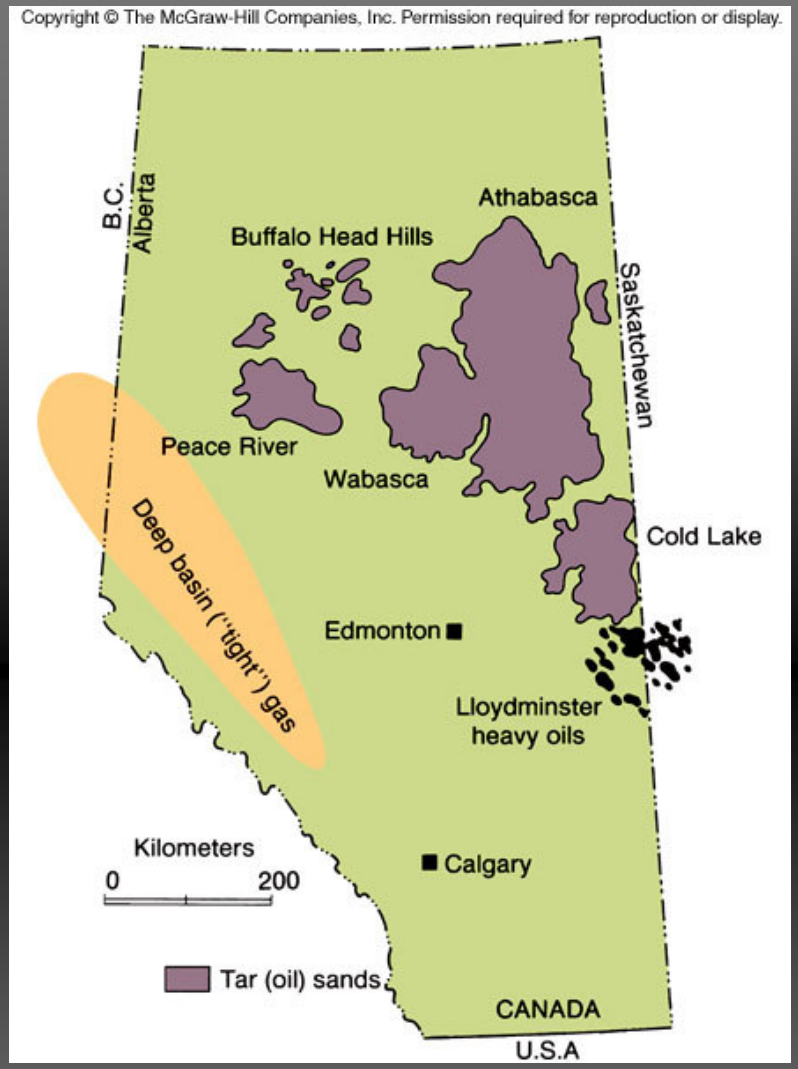
Lands Use Disturbance at Drill Sites

Well Site before Restoration

Restored Well Site

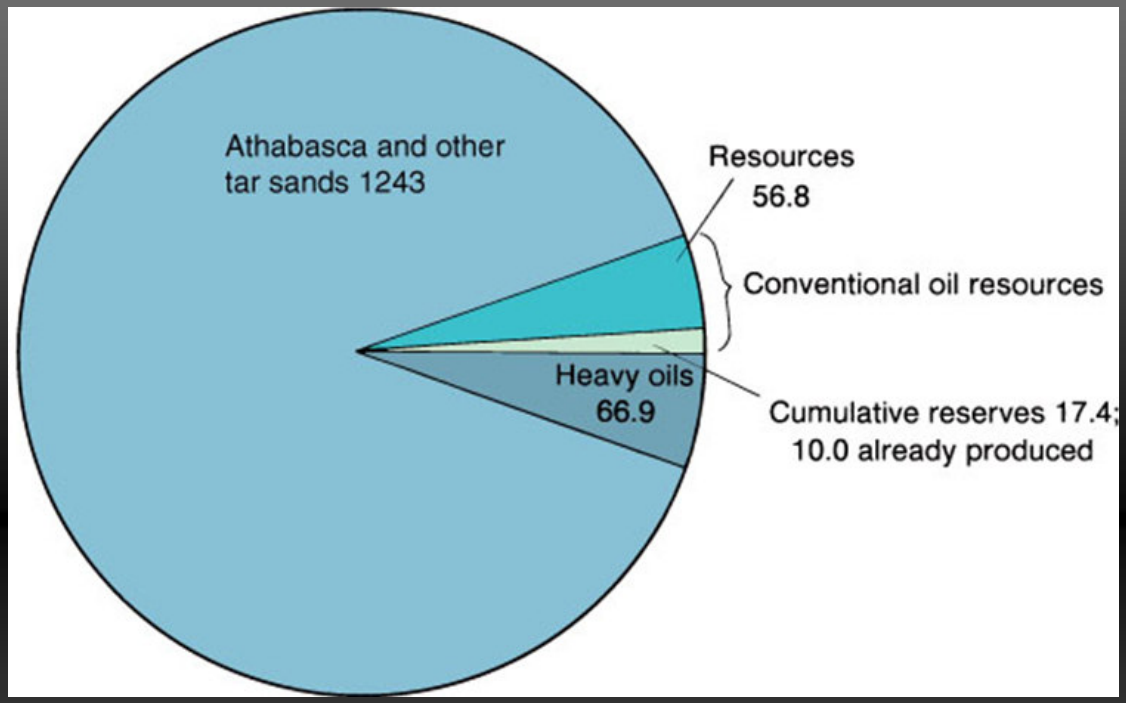
Tar Sand

- Sedimentary rocks containing a thick, semi-solid, tarlike petroleum.
- Tar sand deposits are immature petroleum
- Oil shale and tar sand must be mined and heated to extract the petroleum



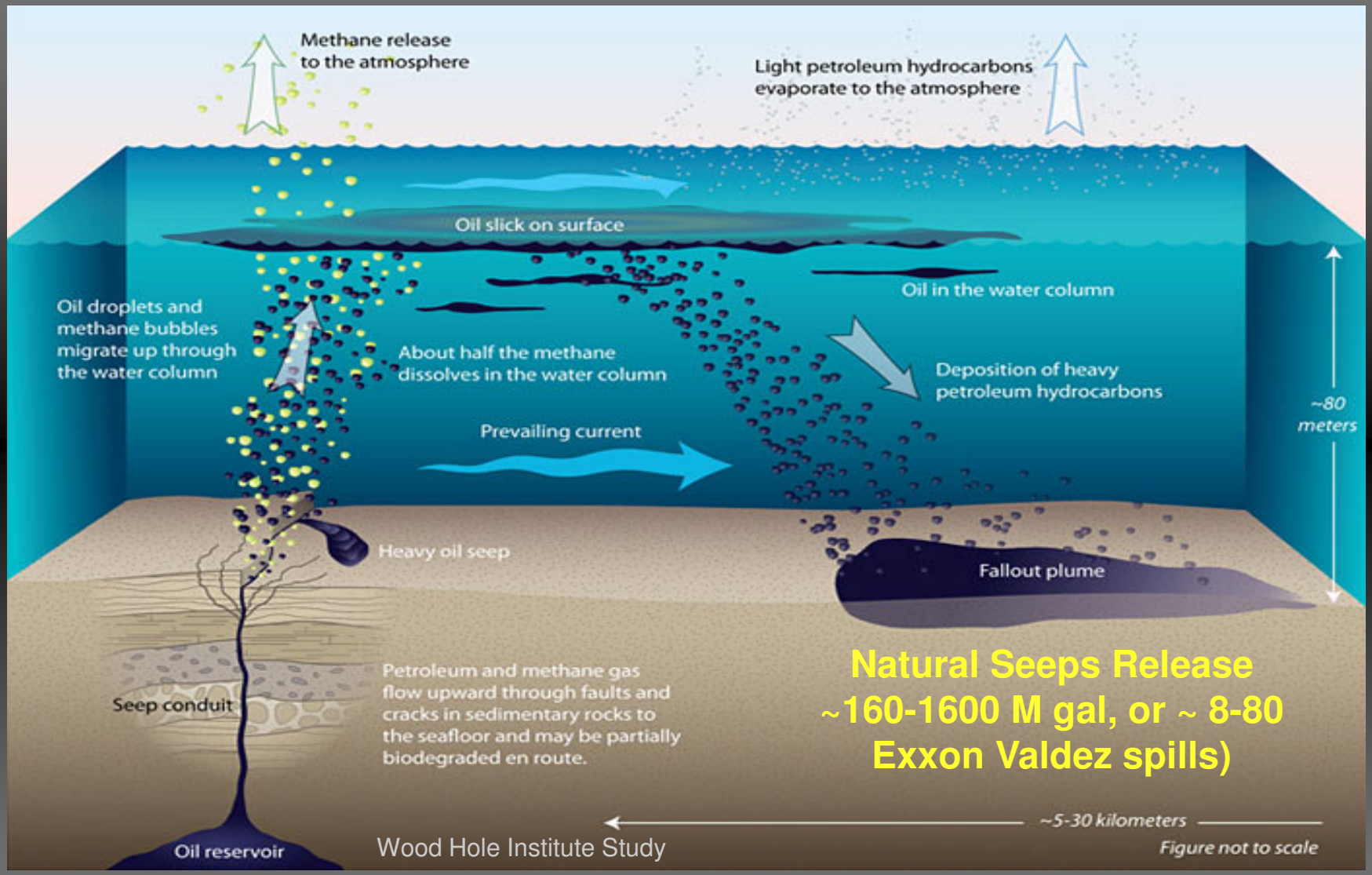
Alberta, Canada

Canadian Petroleum Resources



Keystone Pipeline

Oil Spills – The majority are NATURAL



Wood Hole Institute Study

Oil Spills – The majority are NATURAL

- Anthropogenic accidental spills ~ 10,000 per year in U.S. waters (~15 to 25 million gallons of oil annually)
  - Oil tankers (Exxon Valdez – 20M gal)
  - Drilling accidents (Deepwater Horizon – 200M gal)
  - Disposal of used oil
  - Intentional destruction of pipelines

- Damage Control techniques:
  - Floating barriers and skimmers
  - Fertilize the microorganisms
  - Dispersants and hot steam washing
  - Burn it off

BP DEEPWATER HORIZON

Coal

- Provides about 20% of U.S. energy supply
  - More than 50% of U.S. electric power

- Formation of Coal Deposits
  - **Coal** from remains of land plants
  - Swamp settings ideal with abundant trees, leaves, moss and ferns.
  - Requires **anaerobic conditions (oxygen absent)** to convert organic matter into coal

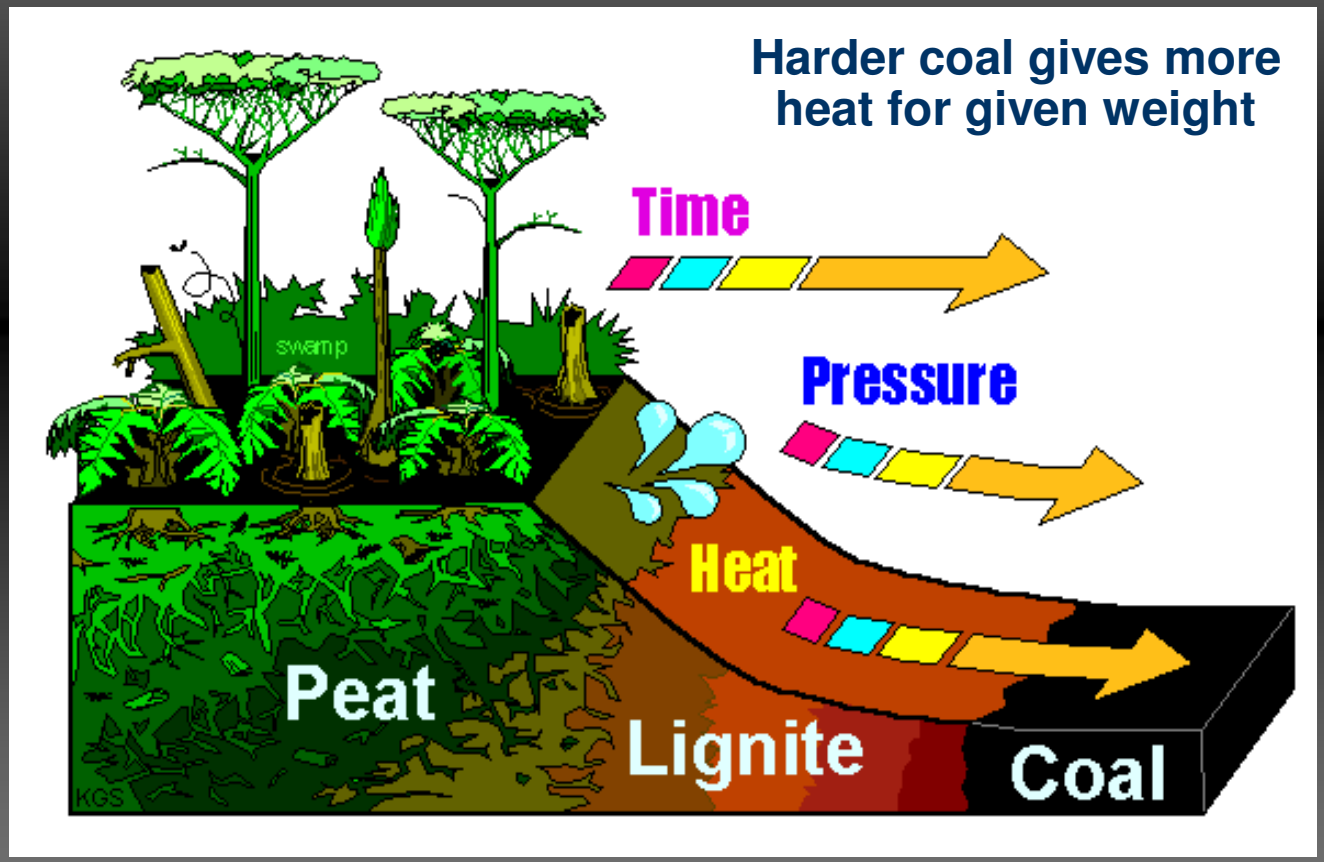
Coal is a nonrenewable resource

- Peat – first combustible product to form (<30% C) at surface with suitable conditions

- Lignite soft brown coal (30-50% C)

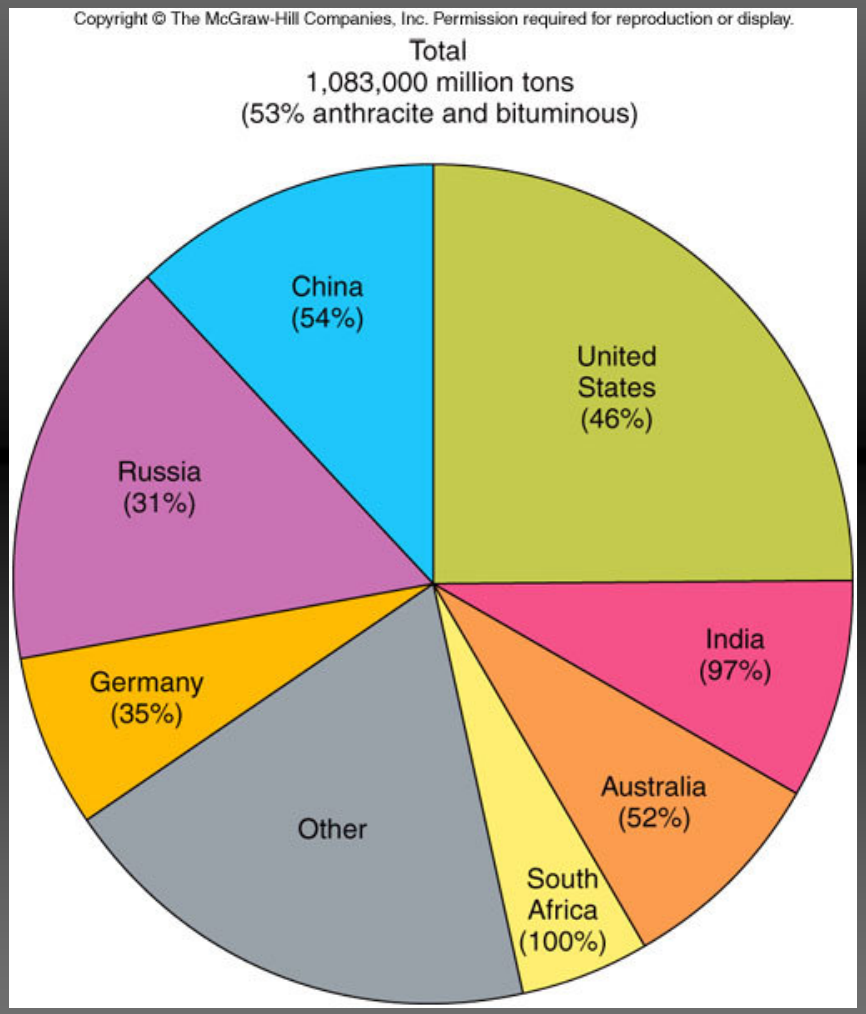
- Bituminous hard coal (50-80% C)

- Anthracite hardest coal (>80% C)

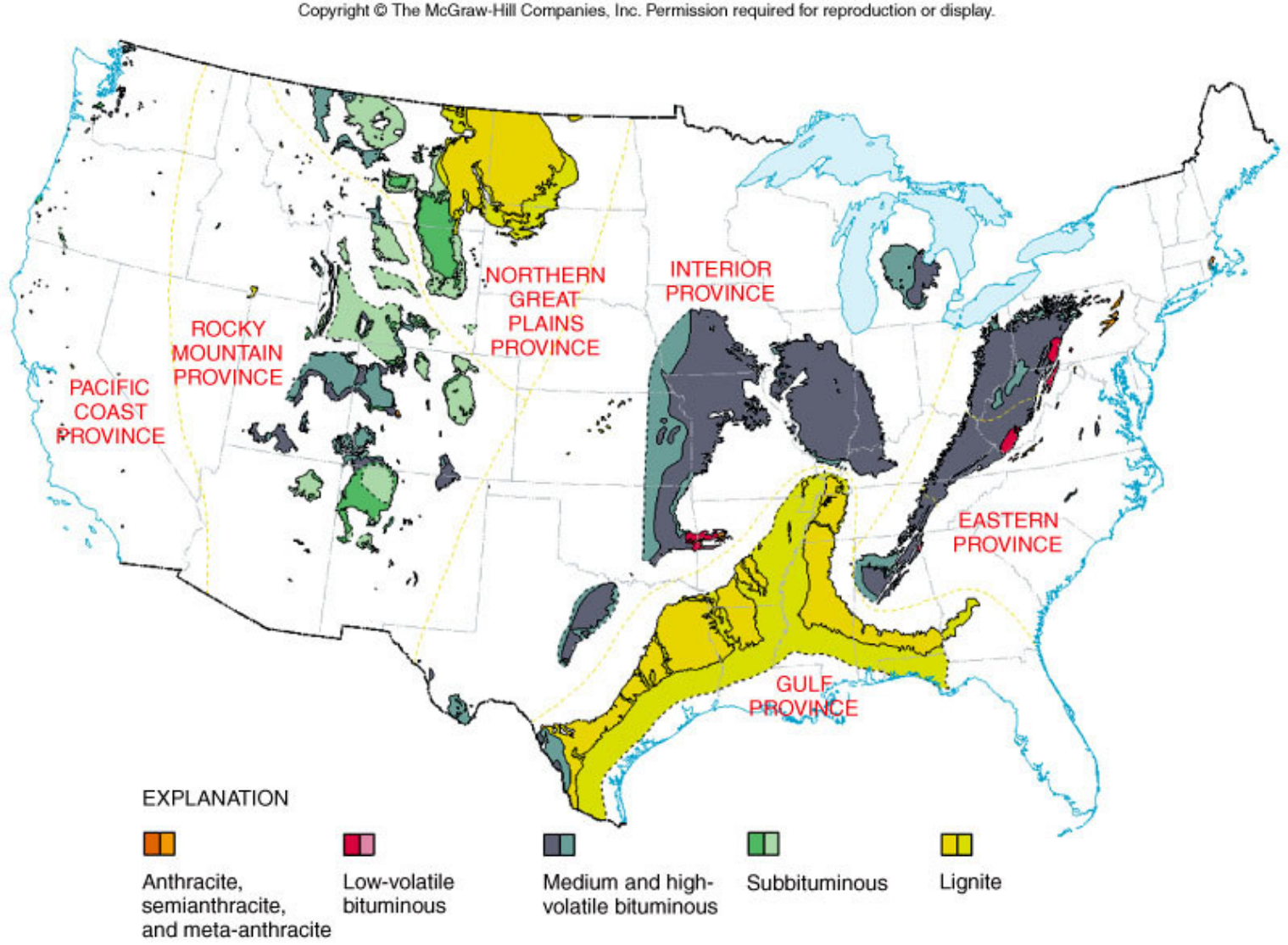


Coal Reserves and Resources

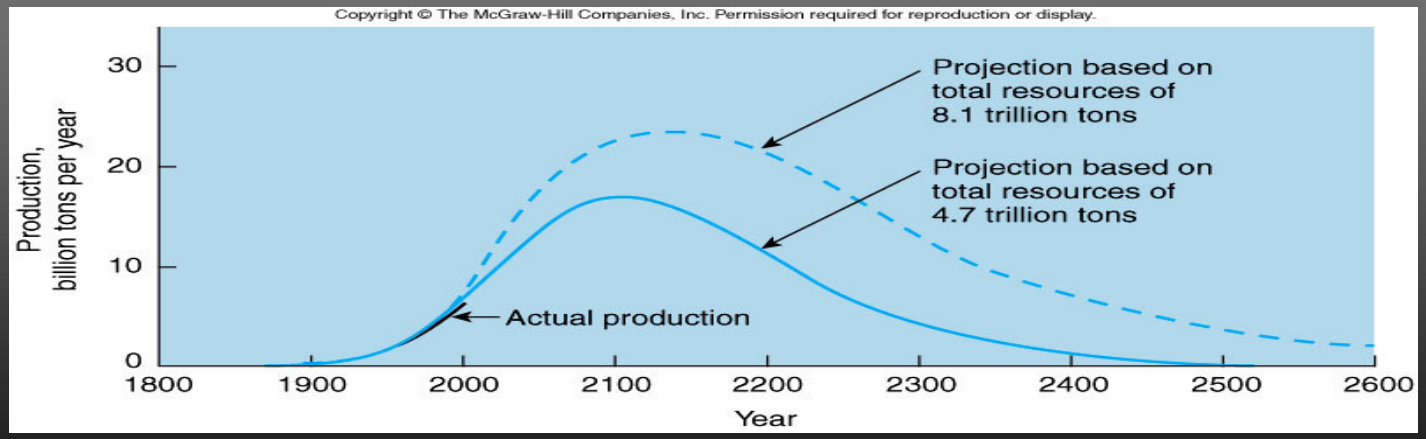
- Estimated world reserves of 1 trillion tons (~10 trillion tons in total resources)
- Estimated U.S. reserves over 270 billion tons of recoverable coal
  - Estimated 2.7 trillion tons in total resources
  - probably 200 year supply

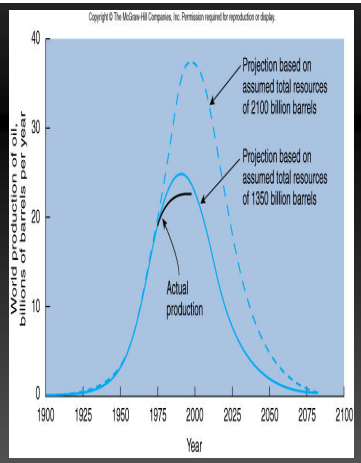


Map of US Coal

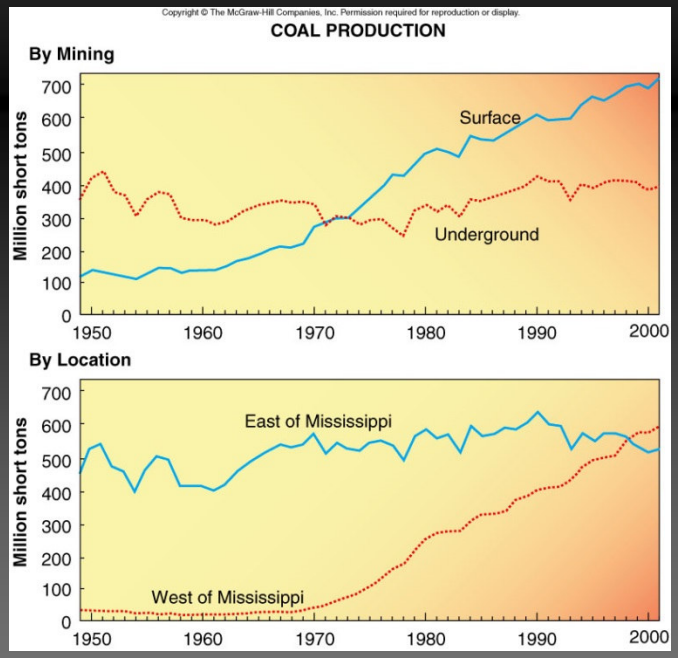


Peak Coal Projections - M. King Hubbert (1971)





Oil



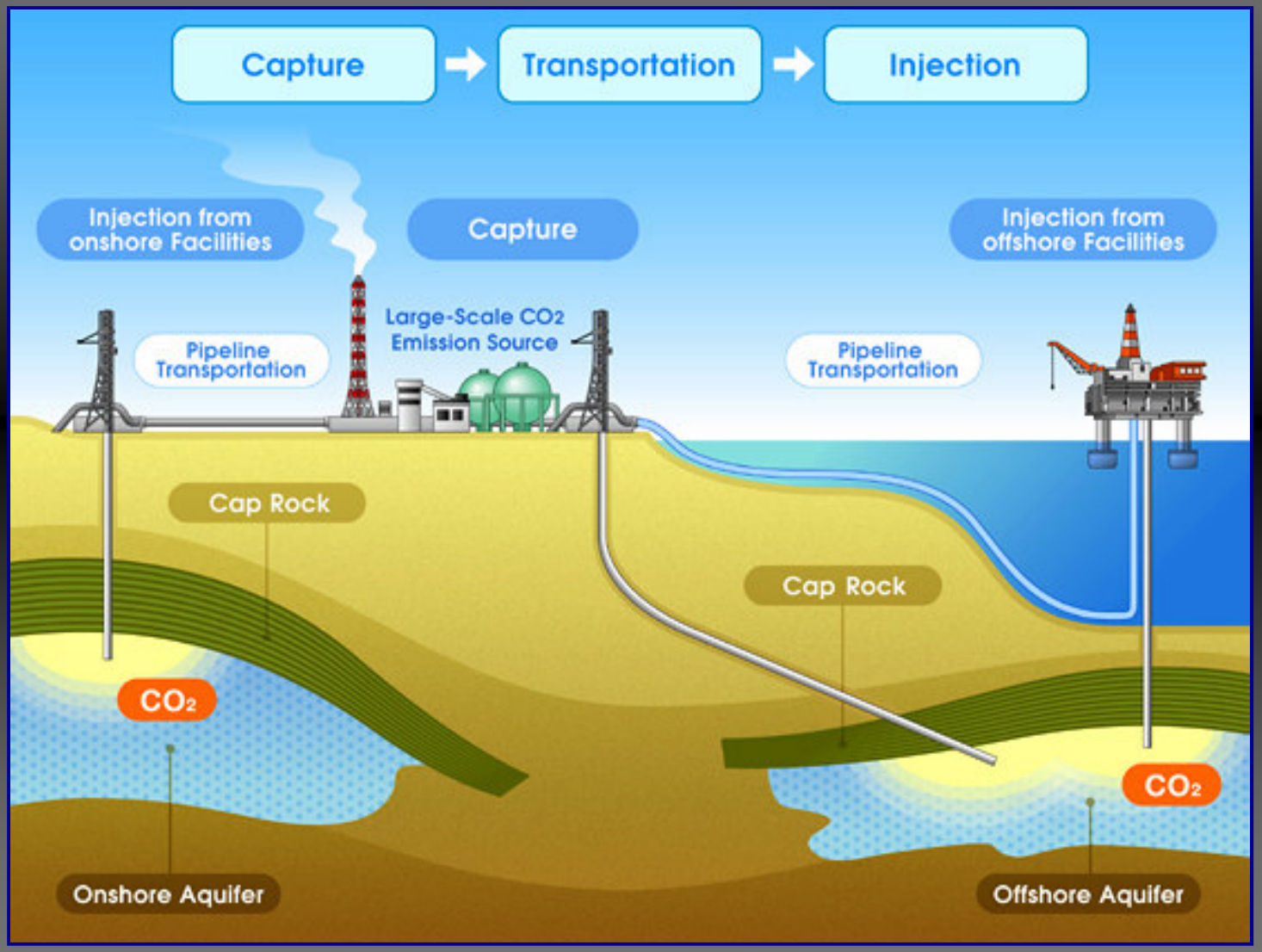
Limitations on Coal Use

- Coal is not currently clean to mine or burn
- Coal is a bulky product difficult transport
- Coal can be converted to a gas by – easier to transport

Environmental Impacts of Coal Use

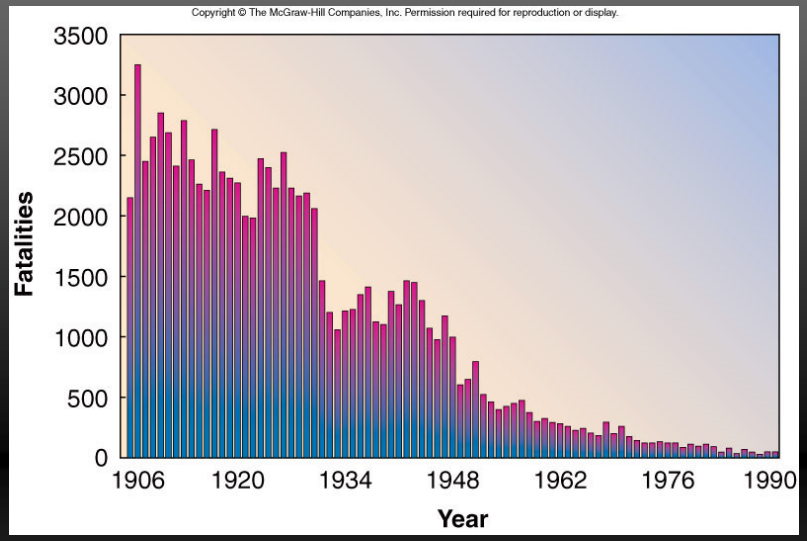
- Produces abundant carbon dioxide when burned
  - Carbon dioxide is a greenhouse gas – New technologies being developed to improve emissions by *sequestering* CO_2
- Liberates sulfur as sulfur dioxide into atmosphere - -
  Acid Rain: sulfur dioxide with atmospheric water produces sulfuric acid
- Ash is liberated from coal upon burning
  - Ash is as much as 20% of the volume of coal
  - Often contains metal such as selenium and mercury

Geological sequestration of CO_2



Other Hazards and Environmental Impacts

- Underground mining of coal is dangerous
  - Mines collapse or natural gas explosion
  - Miners exposure to coal dust
- Strip mining exposes the coal to the weather
  - Rain water and air comes in contact with sulfur in the coal beds or waste rock thereby producing sulfuric acid (acid drainage)
- Coal mine reclamation is required



Ohio strip mine & spoils in Ohio and reclaimed strip mine in N Dakota

D