Concepts for Increasing Geological Storage Space

(Using Insights from Oil and Gas Industry Experience)

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EOR Carbon Management Workshop

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Overview

- Qualifying/Ranking Of Geological Storage Settings
- Sedimentary Settings/Basin Types
- The North American Craton
- The Permian Basin Example

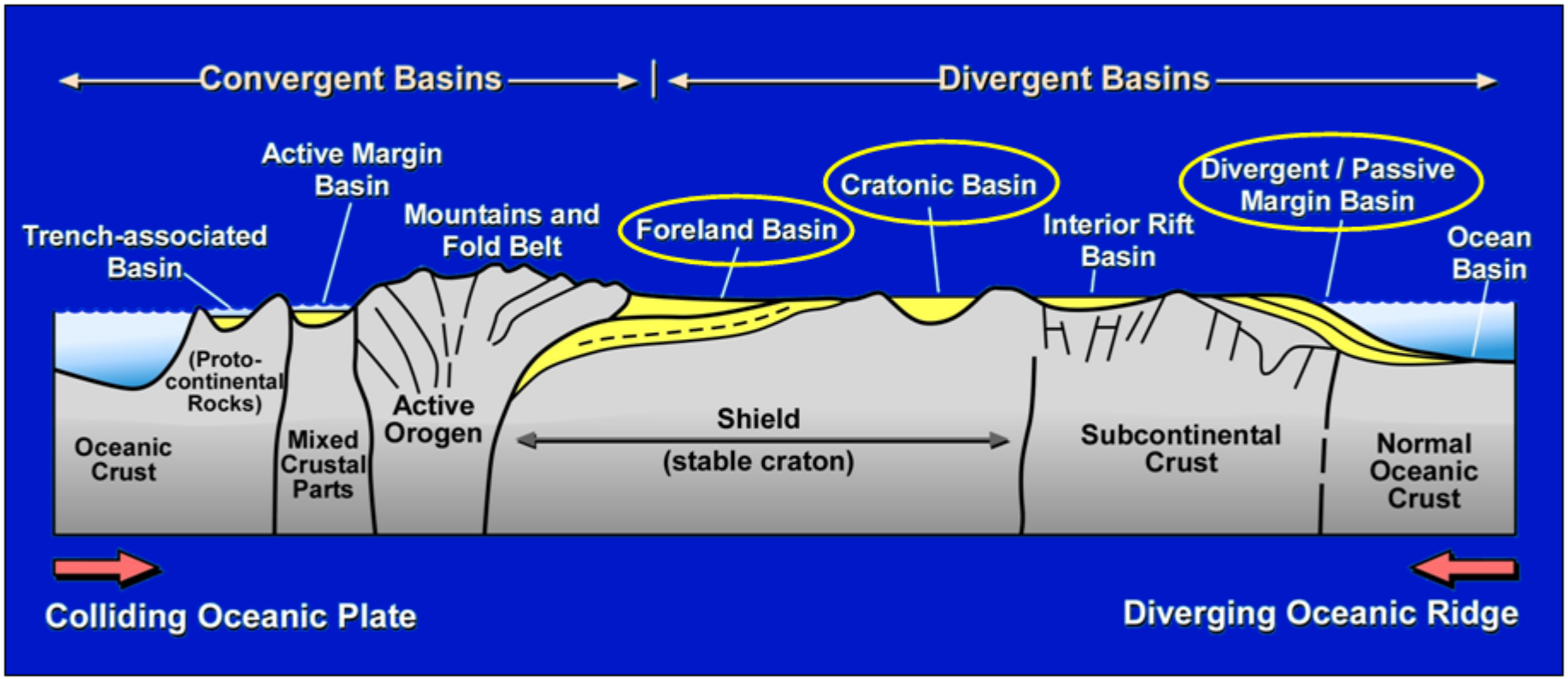
QUALIFYING/RANKING OF GEOLOGICAL STORAGE SETTINGS

- REQUIRED ATTRIBUTES OF GEOLOGICAL SETTINGS FOR STORAGE
  - VOLUMETRICS
  - CONFINEMENT (VERTICAL, LATERAL)
  - SUFFICIENT INJECTION RATES

Sedimentary Basins Generally have these Attributes

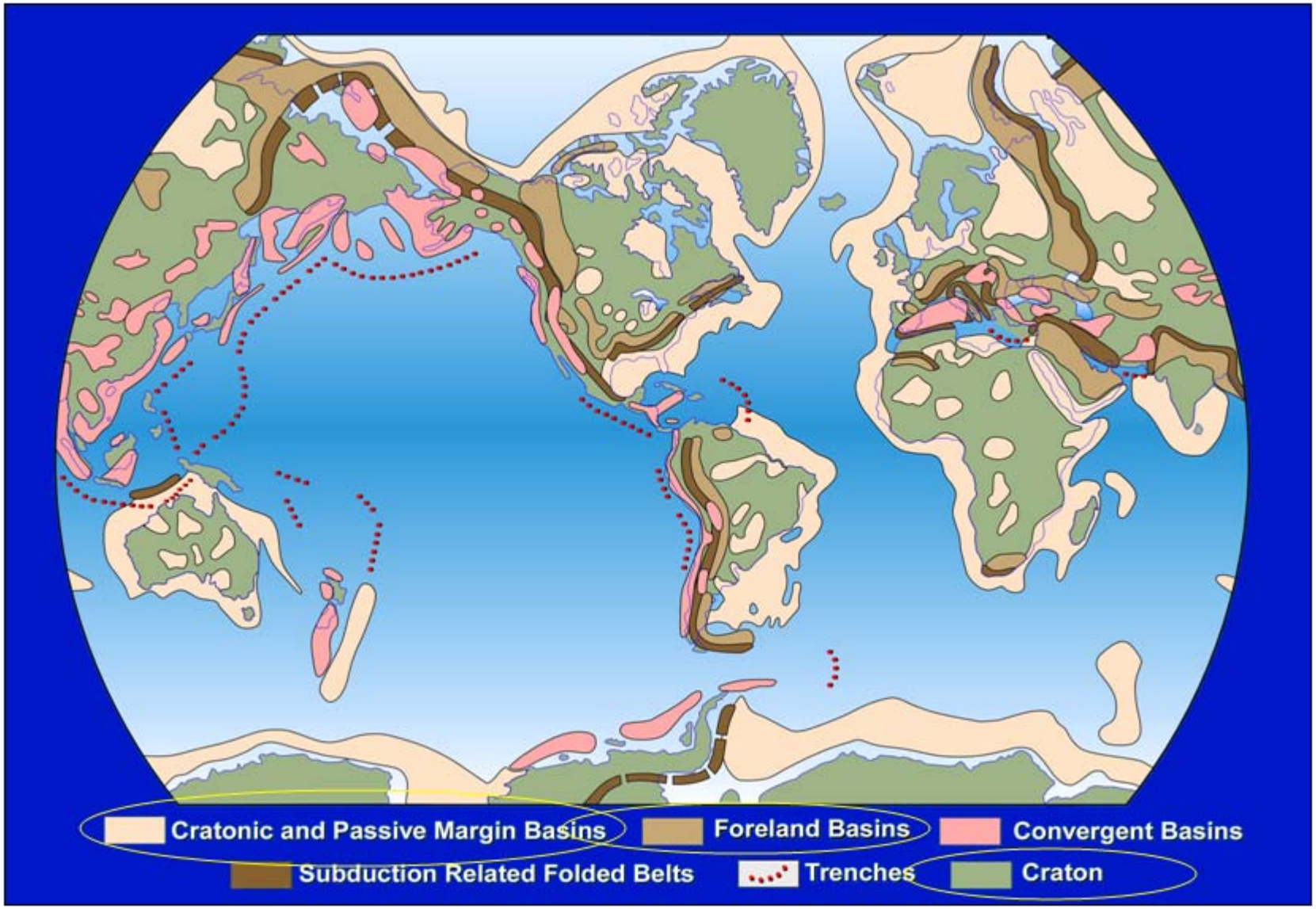
- SEDIMENTARY VS. OTHER SETTINGS
  - PROVEN TRAPPING CHARACTERISTICS (GAS, OIL, CO_2)
  - LARGE, LATERALLY CONTINUOUS RESERVOIRS
  - EXTENSIVE SUBSURFACE DATA BASE
- TYPES OF SEDIMENTARY BASINS
  - DIVERGENT
  - CONVERGENT
  - SALT CAPPED *(SPECIAL CONSIDERATION)*

Cross Sectional Representation of Various Types of Sedimentary Basins



Source: Hitchon et al., 1999

Types of World Distribution of Sedimentary Basins

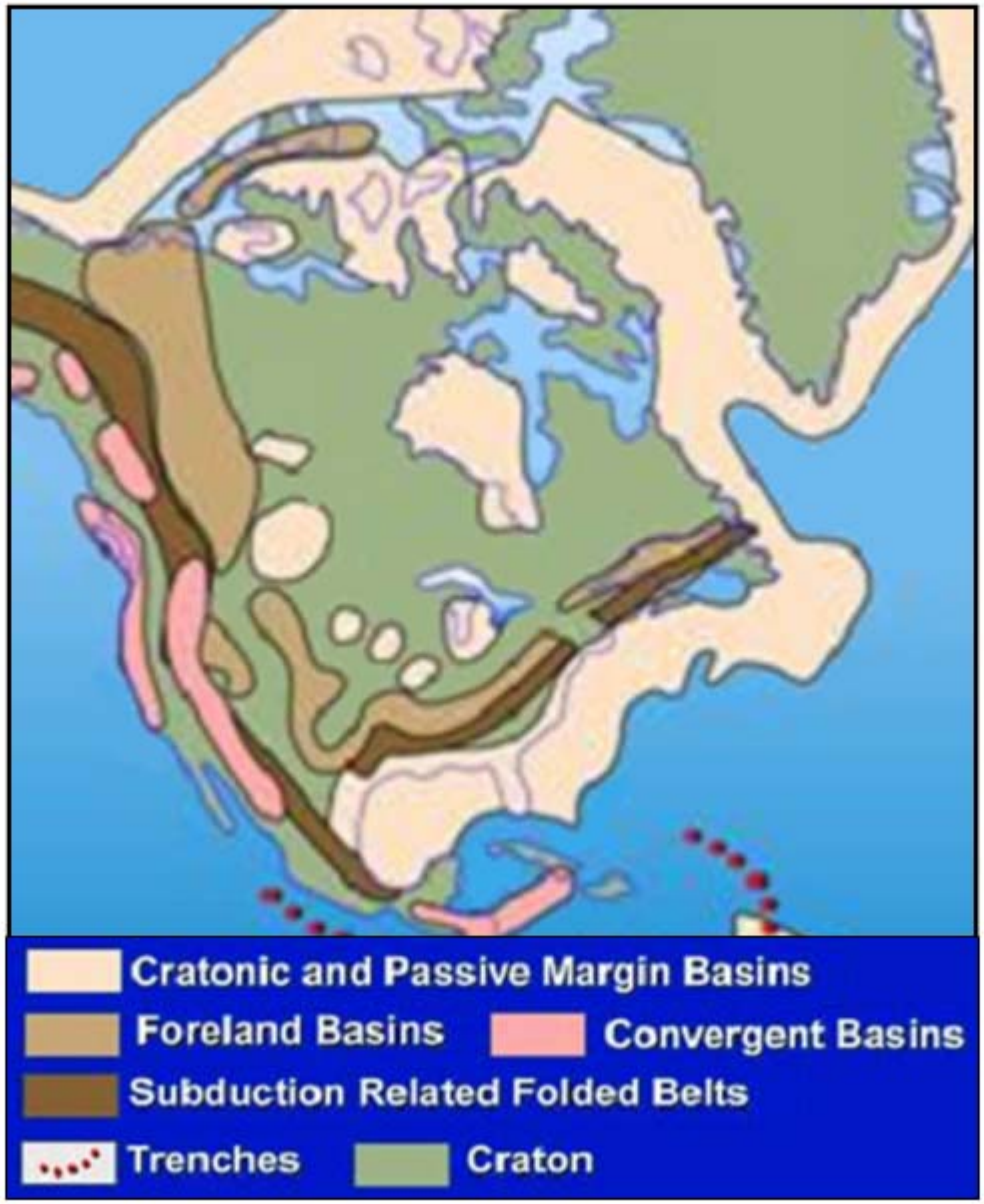


Source: Based on St. John et al., 1984

The North American Craton

Ref: http://commons.wikimedia.org/wiki/Image:North_america_craton_nps.gif

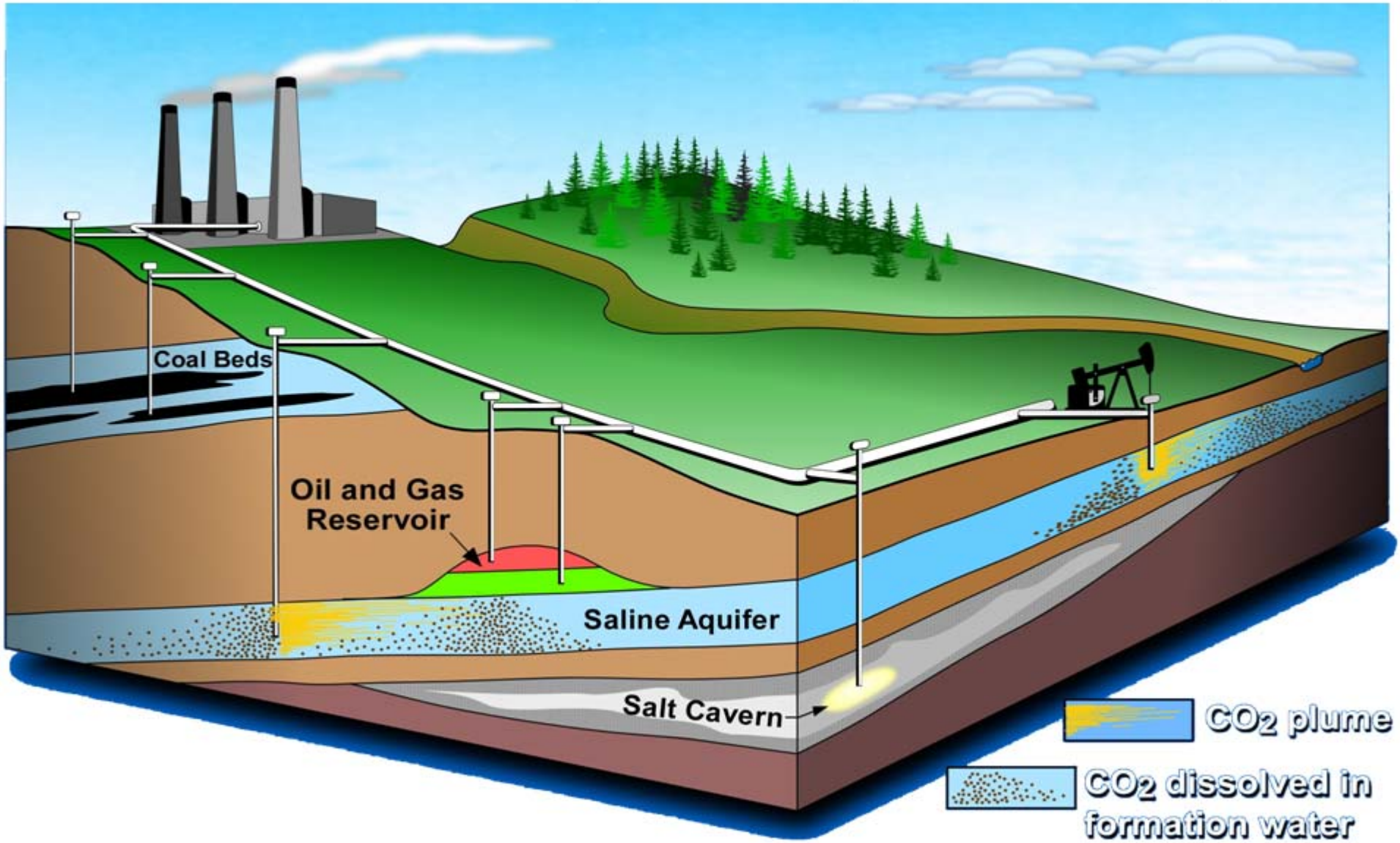
NORTH AMERICAN GEOLOGIC FEATURES



Means of CO_2 Geological Storage

- Gas Reservoirs
- Oil Reservoirs
- Deep Saline Aquifers
- Coal Beds
- Salt Caverns

Means of CO_2 Geological Storage



Types of Projects for CO_2 Geological Storage

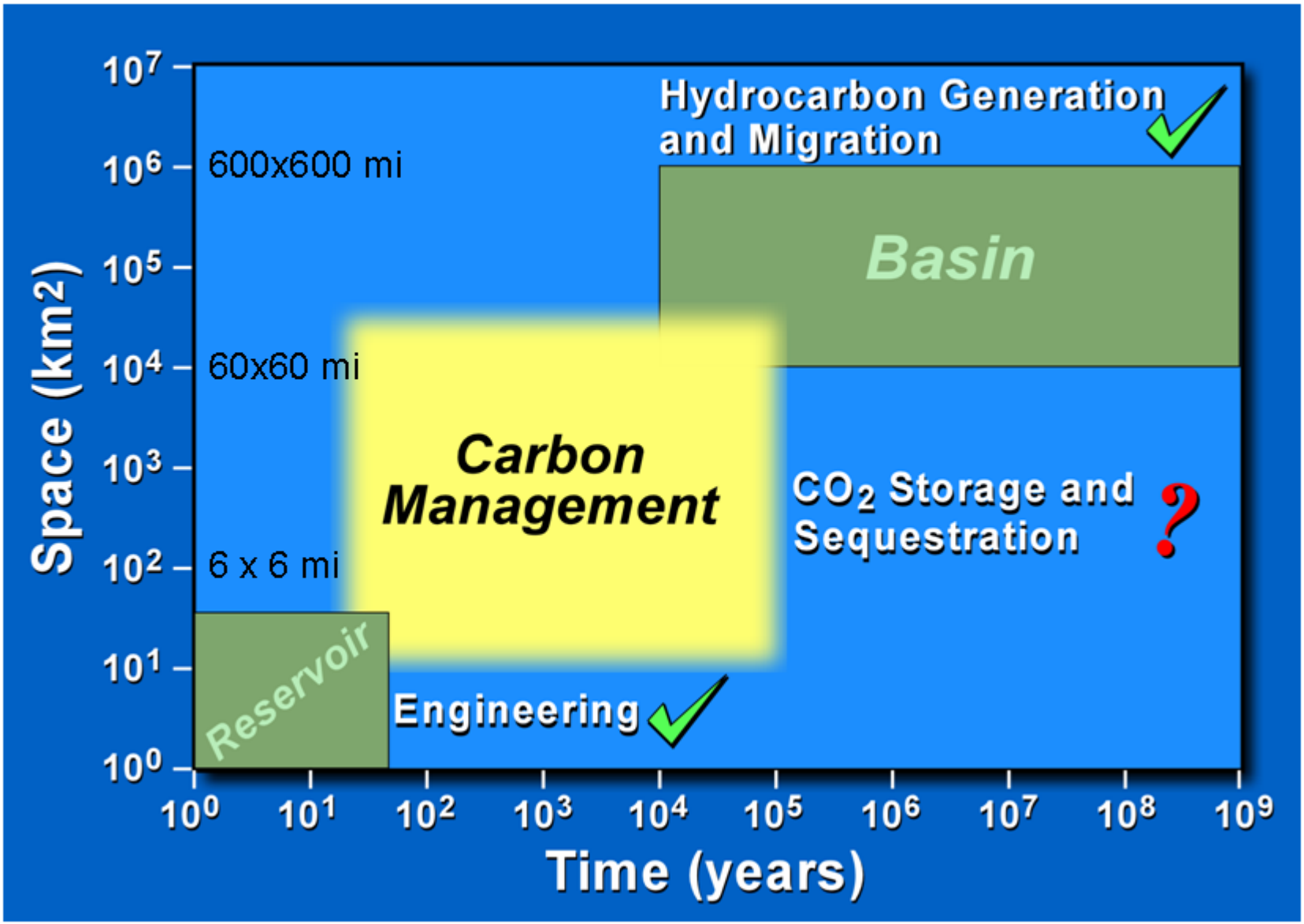
- Depleted Oil Or Gas Reservoirs
- Enhanced Oil Or Gas Recovery (EOR Or EGR)
- Enhanced Coalbed Methane Recovery (ECBMR)
- Aquifer Injection
- Solution-mined Salt Caverns

Scales of Processes and Studies

- For hydrocarbon generation, migration and accumulation:
  basin scale, geological time scale
- For hydrocarbon production and liquid waste disposal:
  a field reservoir scale, human time scale
- For CO_2 geological storage:
  intermediate between the two!

  - **Screening criteria must consider these scales**

Process Scales for CO_2 Geological Storage and Sequestration



Basin and Regional-Scale Screening Criteria

Based on:

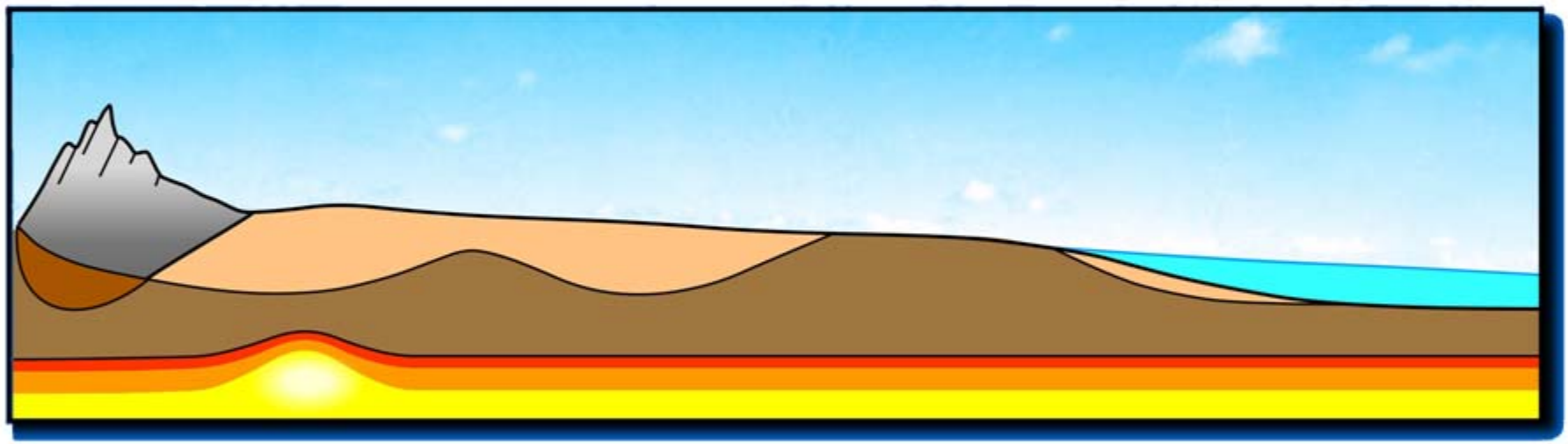
- Geological characteristics
- Hydrodynamic and geothermal regimes
- Basin resources and maturity
- Industry maturity and infrastructure
- Economic and societal aspects

Types of Sedimentary Basins

- **Divergent**
  - Intra-cratonic
  - Passive margin
- **Convergent**
  - Active margin
  - Intra-montane
  - Foreland

Preferred Sedimentary Basins

Intra-cratonic, foreland and passive-margin basins



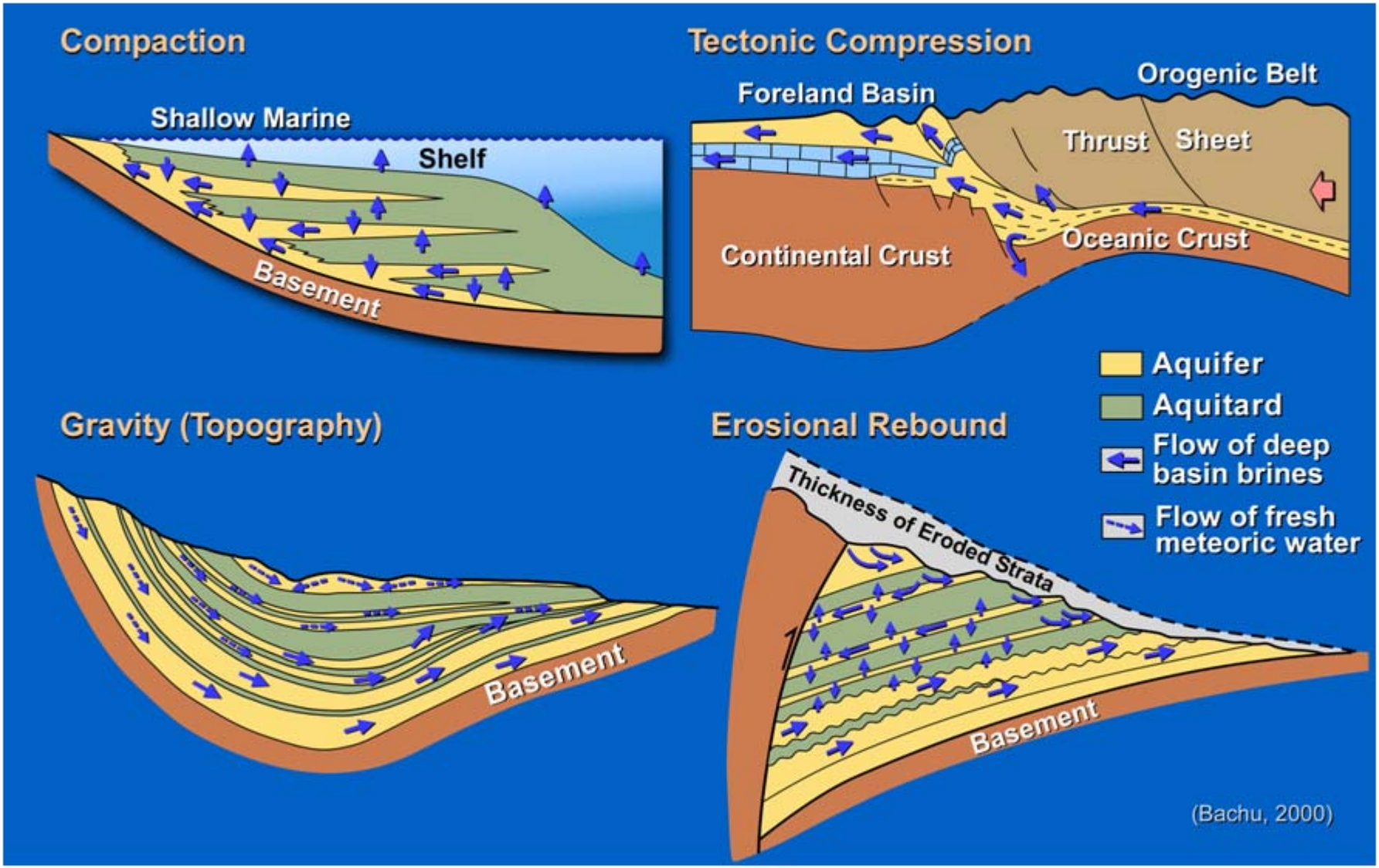
Geological Characteristics of Basins Suitable for CO_2 Geological Storage

- Adequate Depth (>3000’)
- Strong Confining Seals
- Minimally Faulted, Fractured Or Folded
- Laterally Consistent Sedimentary Sequences

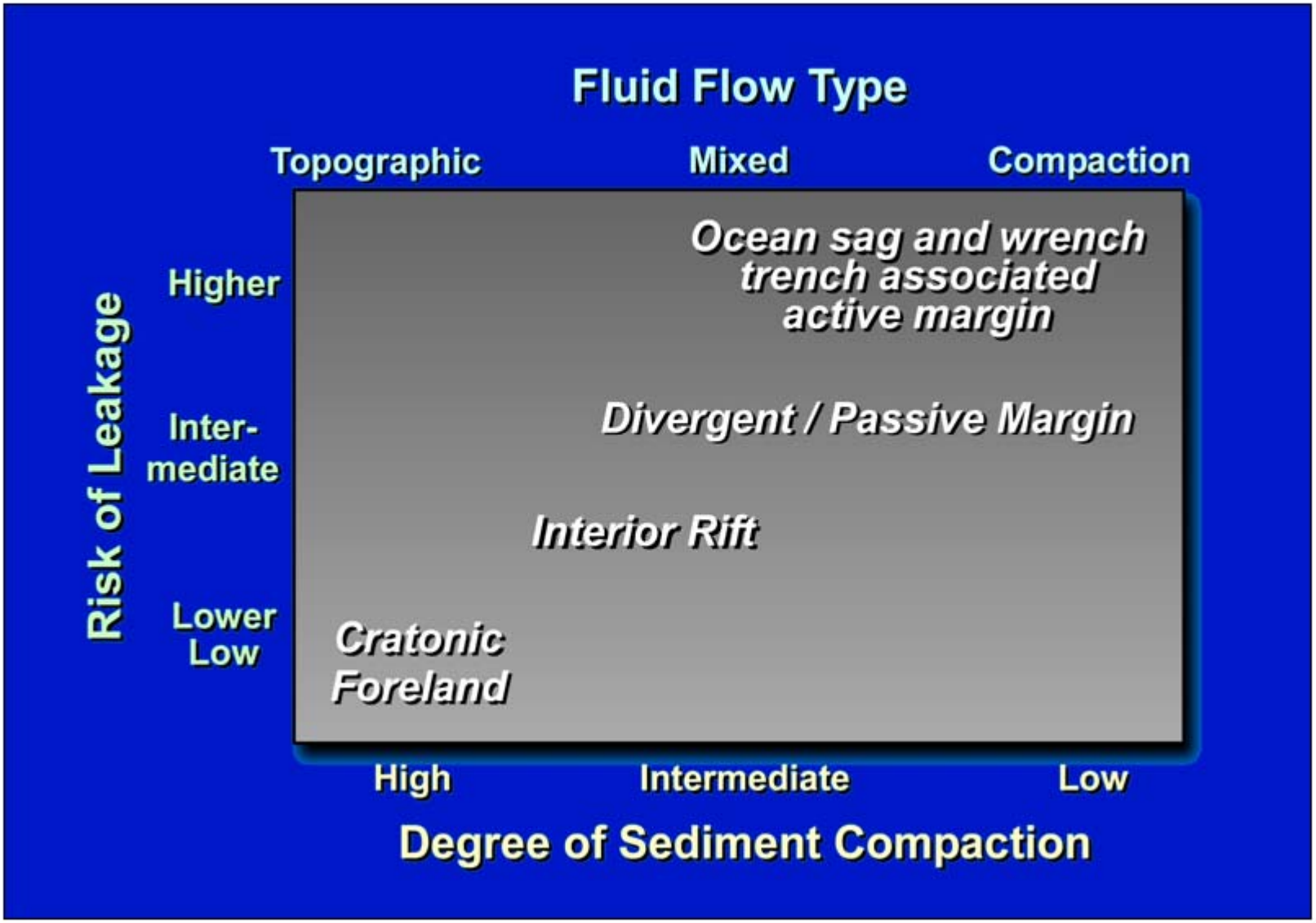
Flow of Formation Waters in Sedimentary Basins

- Driven by sediment compaction on marine shelves
- Driven by tectonic compression in orogenic belts
- Driven by erosional (and glacial) rebound in foreland and intra-cratonic basins
- Driven by topography in intra-montane, foreland and intra-cratonic basins
- Driven by hydrocarbon generation and other internal overpressuring processes

Types of Fluid Flow in Sedimentary Basins

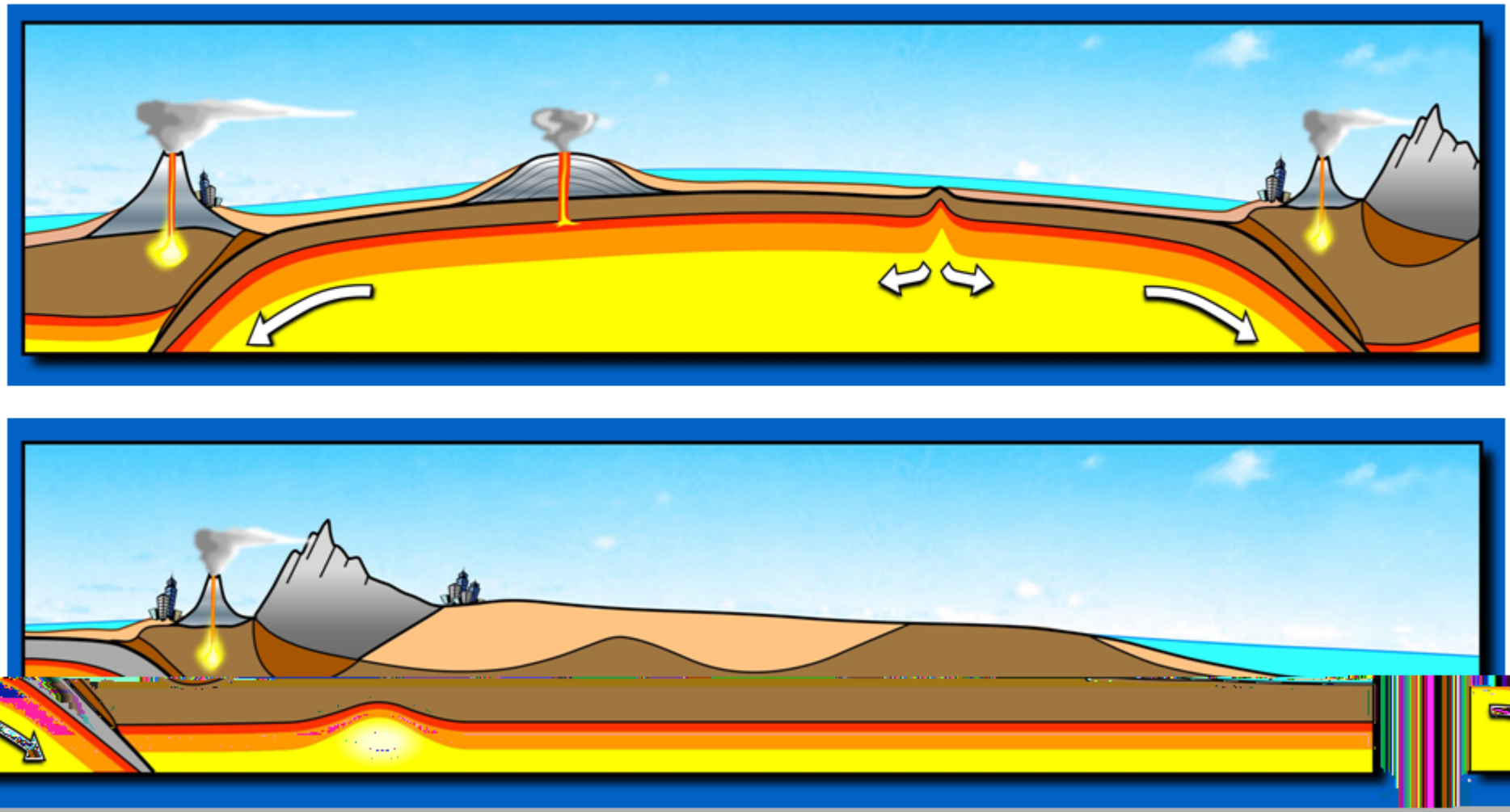


Risk of Leakage in Sedimentary Basins



Source: Hitchon et al., 1999

Heat Flow in Pacific and North American Plates



Basin Maturity

Defined by fossil-energy potential (oil and gas, coals) and degree of exploration and production

Mature:

- Rich in Energy resources, advanced production

Poor:

- No or poor in hydrocarbon resources

Industry Maturity and Infrastructure

Developed continental basins:

- Access roads, pipelines, wells

Developed marine basins:

- Drilling and production platforms

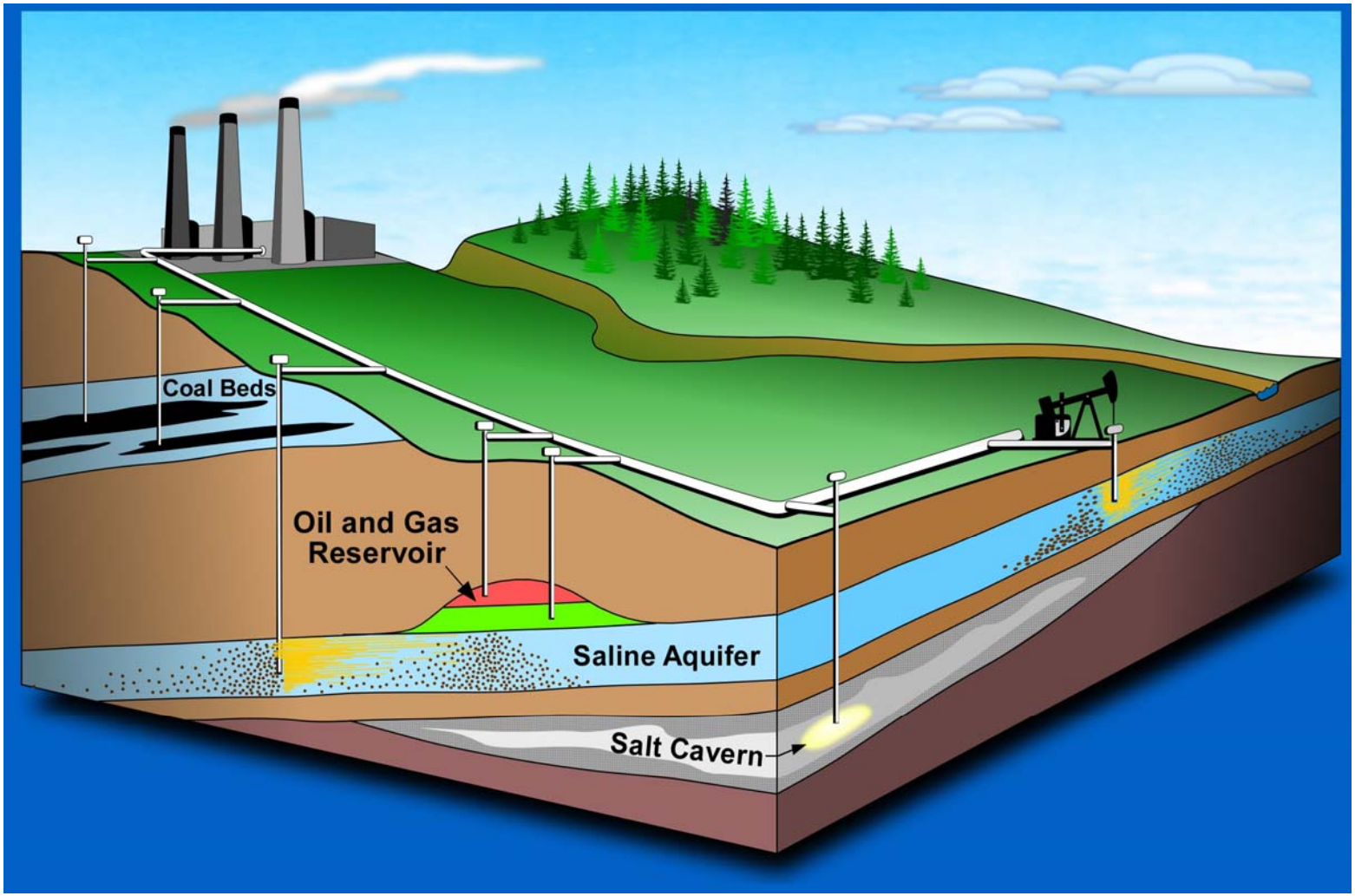
Suitability of Sedimentary Basins for CO_2 Geological Storage

	Mature Basin	Immature Basin
Geology	*Known*	*Poorly defined*
Hydrodynamic and Geothermal Regimes	*Generally Known*	*Unknown*
Hydrocarbon Reservoirs	*Mostly Discovered*	*Very Few Discovered*
Hydrocarbon Production	*Significant*	*Incipient*
Infrastructure	*Well Developed*	*Rudimentary*

Source: Bachu, 2002

Preferred Sedimentary Basins

Mature, with developed infrastructure



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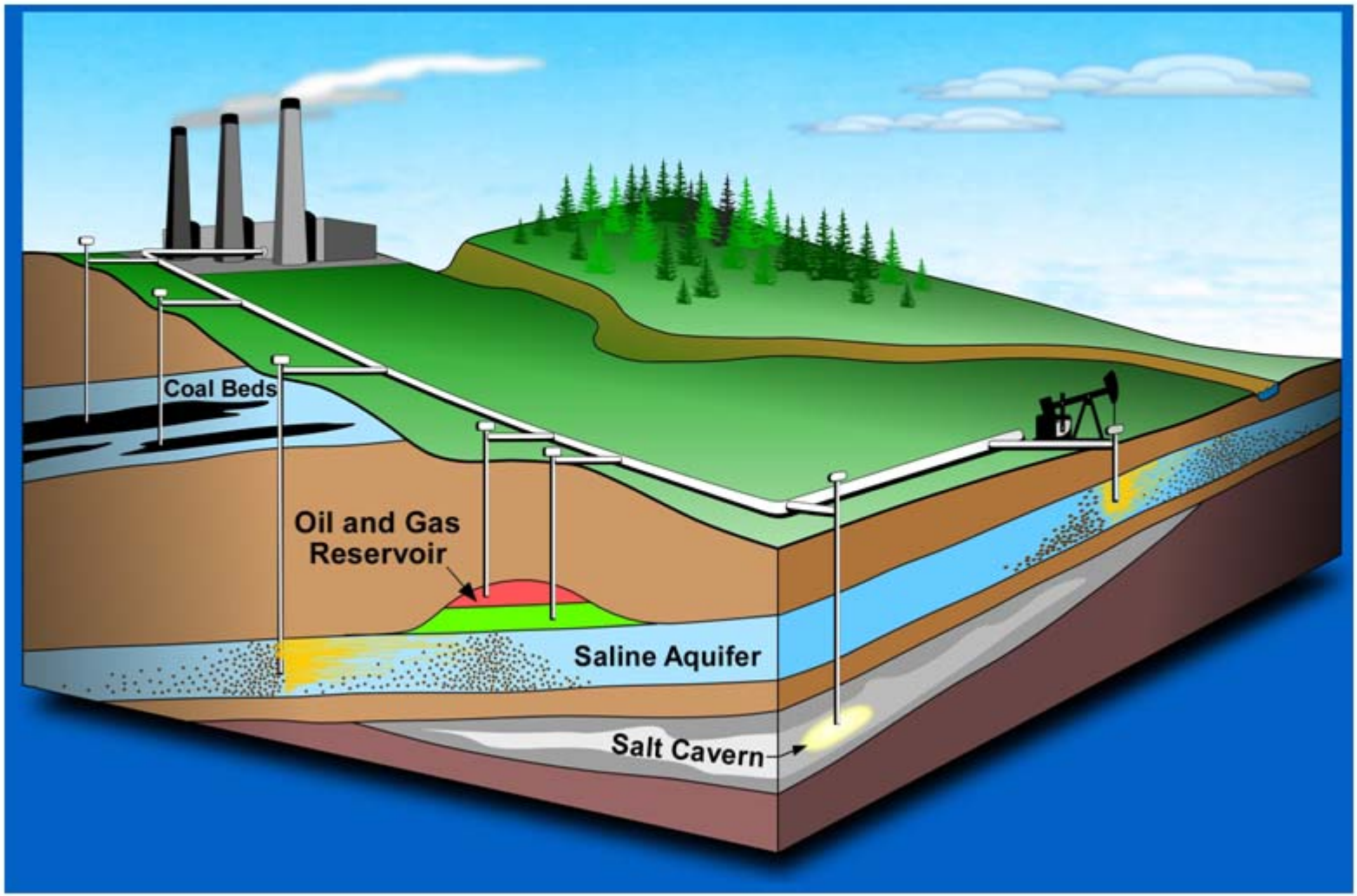

Economic and Societal Aspects

Cost:

- Affected by basin location, marine or continental, climatic conditions, transportation distances, injection depth

Legal:

- Jurisdiction over resources, liability, regulatory regime

Public Acceptance:

- Proximity to population centers, accept or reject projects

Criteria for Assessing Sedimentary Basins for CO_2 Storage - 1

Criterion	Classes				
	1	2	3	4	5
Tectonic Setting	*Convergent basin*	*Convergent intramontane*	*Divergent continental shelf*	*Divergent foredeep*	*Divergent cratonic*
Size	*Small*	*Medium*	*Large*	*Giant*	
Depth	*Shallow (<1500m)*	*Intermediate (1500-3500m)*	*Deep (>3500m)*		

Source: Bachu, 2003

Criteria for Assessing Sedimentary Basins for CO_2 Storage - 2

Criterion	Classes				
	1	2	3	4	5
Geology	*Extensively faulted & fractured*	*Moderately faulted & fractured*	*Limited faulting & fracturing, extensive shales*		
Hydrogeology	*Shallow, short flow systems, or compaction*	*Intermediate flow systems*	*Regional, long range flow systems; topography or*		

Criteria for Assessing Sedimentary Basins for CO_2 Storage - 3

Criterion	Classes				
	1	2	3	4	5
Hydrocarbon Potential	None	Small	Medium	Mature	Over-mature
Maturity	Unexplored	Exploration	Developing		
Coal & CBM	None	Deep (>800m)	Shallow (200-800m)		
Salts	None	Domes	Beds		

Source: Bachu, 2003

Criteria for Assessing Sedimentary Basins for CO_2 Storage - 4

Criterion	Classes				
	1	2	3	4	5
On/Off Shore	Deep Offshore	Shallow Offshore	Onshore		
Climate	Arctic	Subarctic	Desert	Tropical	Temperate
Accessibility	Inaccess-ible	Difficult	Accept-able	Easy	Known
Infrastructure	None	Minor	Moderate	Extensive	Known
CO_2 Sources	None	Few	Moderate	Major	Known

Source: Bachu, 2003

Local-Scale Screening Criteria

Same criteria as for basin and regional-scale

Additional Criteria:

- Safety and effectiveness
- Economic
- Technical specific

Geological Characteristics of Sites Suitable for CO_2 Geological Storage

- Adequate volume (thickness and porosity)
- Adequate permeability
- Confining unit

Safety and Effectiveness Criteria

- Avoid contamination of energy, mineral and groundwater resources
- Avoid risk to life (plants, animals, humans)
- Avoid, or at least minimize leakage for the desired time period

Economic Criteria

- Potential for additional energy production (EOR, EGR, ECBMR)
- Penalty avoidance by meeting regulatory requirements
- Avoidance of very deep sites that increase cost of drilling and compression
- Access and surface infrastructure
- Location near CO_2 source to minimize transportation costs
- Avoidance of land and subsurface use conflicts

Criteria Specific to Oil and Gas Reservoirs

Should have sufficient capacity without raising reservoir pressure above the initial pressure

BY THE VERY NATURE OF DEEP SALINE AQUIFER INJECTION, ONE WILL HAVE TO ALLOW IN THAT CASE (DOUBLE STANDARD?)

Criteria Specific to Enhanced Oil Recovery

- Light oil (25 to 48 °API)
- Reservoir pressure greater than Minimum Miscibility Pressure (MMP)
- Preferably thin net pay (<20 m) or interbedded thicker payzones
- “Sweepable” Reservoir

Criteria Specific to Enhanced Coalbed Methane Recovery

- Sufficient permeability (several milidarcies and higher)
- Temperatures below the CO_2 critical point (less than 31 °C {88 °F})
- Thick coal seams
- Minimum faulting and folding of the coal seam
- Low water saturation

Source and Sink Matching

Combines *geological, engineering, safety, economic and societal criteria* in matching CO_2 sources with potential sites for CO_2 geological storage

Additional Criteria for Source-Sink Matching

- Volume, purity and rate of the CO_2 stream
- Proximity and right of access
- Infrastructure for capture, delivery and injection
- Injection, and where appropriate, production strategies
- Presence of energy, mineral and groundwater resources
- Terrain and right of way
- Proximity to population centers
- Expertise and know-how

Conclusions

Geological storage of CO_2 is a *technologically feasible* means of reducing CO_2 emissions to the atmosphere if *proper site selection methods* are applied, combining geoscience, engineering, economics and societal criteria for the selection of CO_2 storage sites

Preferred Sedimentary Basins

Intra-cratonic, foreland and passive-margin basins