Basin Analysis

Basin Analysis

- Introduction
- Mechanisms of Basin Formation
- Basin Classification
- Basins and Sequence Stratigraphy
- Summary

Introduction

- Basin analysis - Study of sedimentary rocks to determine:
  - Subsidence history
  - Stratigraphic architecture
  - Paleogeographic evolution
- Tools:
  - Geology (outcrops, wireline logs, core)
  - Geophysics (seismic, gravity, aeromag)
  - Computers (modeling, data analysis)

Introduction

- What is a basin?
  - Repository for sediment
  - Formed by crustal subsidence relative to surrounding areas
    - Surrounding areas sometimes uplifted
  - Many different shapes, sizes and mechanisms of formation

Introduction

- Zonation of the Earth – Composition
  - Crust
  - Mantle
  - Core

Introduction

- Zonation of the Upper Earth – Rheology
  - Lithosphere
    - Rigid outer shell
    - Crust and upper mantle
  - Asthenosphere
    - Weaker than lithosphere
    - Flows (plastic deformation)

Introduction

- Zonation of the Upper Earth – Rheology
  - Vertical motions (subsidence, uplift) in sedimentary basins are primarily in response to deformation of lithosphere and asthenosphere

Introduction

- Plate motions
  - Plate-plate interactions can generate vertical crustal movements
  - We will examine basins according to their positions with respect to plate boundaries and plate-plate interactions
  - "Wilson Cycle" – opening and closing of ocean basins

Introduction

- Three types of plate boundaries:
  - Divergent – plates moving apart
    - Mid-ocean ridges, rifts
  - Convergent – plates moving towards each other
    - Subduction zones
  - Conservative – plates move parallel to each other
    - Strike-slip systems

Mechanisms of Basin Formation

- Major mechanisms for regional subsidence/uplift:
  - Isostatic – changes in crustal or lithospheric thickness
  - Loading – by thrust sheets, volcanic piles, sediment
  - Dynamic effects – asthenospheric flow, mantle convection, plumes

Mechanisms of Basin Formation

- Isostatic Processes:
  - Crustal thinning
    - Extensional stretching, erosion during uplift, magmatic withdrawal
  - Mantle-Lithosphere Thickening
    - Cooling of lithosphere, following cessation of stretching or cessation of heating

Mechanisms of Basin Formation

- Isostatic Processes:
  - Crustal densification
    - Density increase due to changing pressure/temperature conditions and/or emplacement of higher density melts into lower density crust

Mechanisms of Basin Formation

- Loading:
  - Local isostatic compensation of crust and regional lithospheric flexure
  - Dependent on flexural rigidity of lithosphere

Mechanisms of Basin Formation

- Loading:
  - Sedimentary or Volcanic Loading
  - Tectonic loading
    - During overthrusting and/or underpulling
  - Subcrustal loading
    - Lithospheric flexure during underthrusting of dense lithosphere

Mechanisms of Basin Formation

- Dynamic effects:
  - Asthenospheric flow
    - Descent or delamination of subducted lithosphere
  - Mantle convection
  - Plumes

Basin Classification

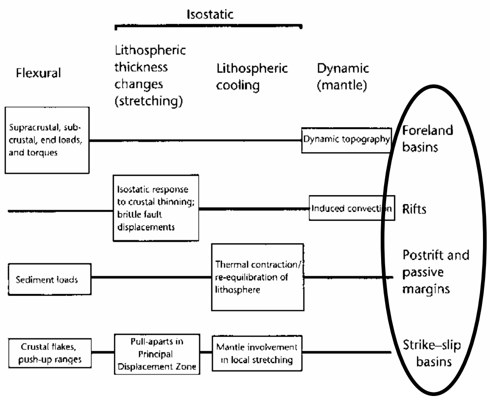
- Many different classification systems have been proposed
- Principal factors:
  - Position of the basin in relation to plate margins
  - Crustal/lithospheric substratum
    - Oceanic, continental crust
  - Type of plate boundary

Basin Classification

- Ingersoll and Busby (1995): 26 different types of basin (see handout)
- Divided into various settings
  - Divergent
  - Intraplate
  - Convergent
  - Transform
  - Hybrid

Basin Classification

- Alternate approach (Allen and Allen, 2005): focus on basin-forming processes
  - What causes subsidence?



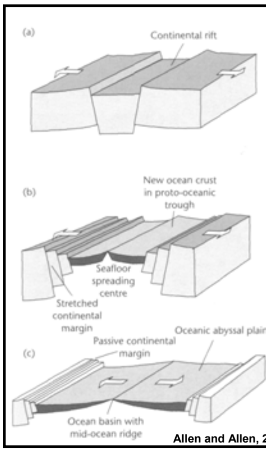
Allen and Allen (2005)

Basin Classification

- This course – hybrid approach:
  - What causes subsidence?
  - What is tectonic setting?
- We do not have time to cover all types of basins
  - Focus on selected basin types

Basin Classification

- Basins can be related to tectonic setting
  - Position with respect to plate boundary
  - Nature of plate boundary
- "Wilson Cycle"



Allen and Allen, 2005

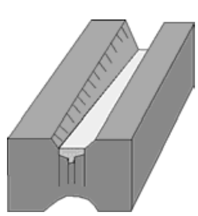
<u>Divergent Plate Boundaries</u>

Continental rifting (a) may lead to opening of an ocean with a mid-ocean ridge (b, c)

Rift basin evolves into passive margin

Basin Classification

- Rift Basins
  - Elongate, valleys bounded by normal faults
    - Few km -> 10s of km wide
    - Length – up to 1000s of km
  - Occur in many plate settings, but most common in divergent settings

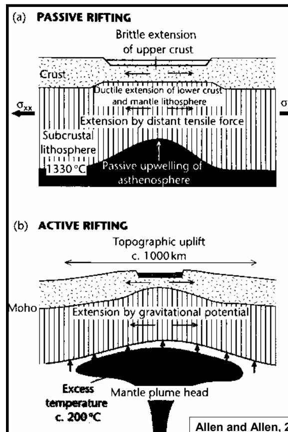


Basin Classification

- Rift Basins
  - Seismic studies indicate rifts overlie thinned crust
  - Evidence for thermal anomalies at depth:
    - Negative Bouguer gravity anomalies
    - High heat flow
    - Bimodal volcanic activity

Basin Classification

- **Rift Basins**
  - **Active rifting:**
    - **Mantle upwelling causes crustal thinning (heating)**
    - **Thinning leads to uplift**
    - **Uplift leads to tension and rifting**
  - **Passive rifting:**
    - **Regional extension causes failure**
    - **Hot mantle rocks rise and penetrate lithosphere**



Allen and Allen, 2005

Passive Rifting – regional extension causes rifting, upwelling of hot mantle follows.

Example: Rio Grande

Active Rifting – Upwelling of hot mantle leads to uplift and extension.

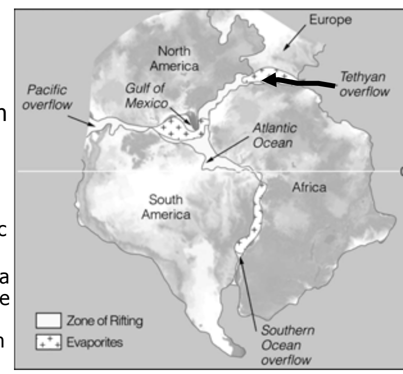
Example: East African Rift

Basin Classification

- **Rift Basins**
  - **Rift fill commonly consists of "continental" deposits**
    - **Fluvial, lacustrine, alluvial fans**
  - **Evaporites may form if rift valley/basin is located in a hot, dry area**
    - **Invasion of the sea**
    - **Closed drainage basins**
  - **Volcanic rocks, and associated intrusions, may be present**

Early Mesozoic Evaporites

- Evaporites accumulated in shallow basins
  - as Pangaea broke apart during the Early Mesozoic
  - Water from the Tethys Sea flowed into the Central Atlantic Ocean

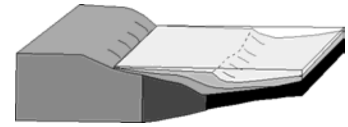


Basin Classification

- **Continued rifting can lead to formation of oceanic crust – opening of ocean basin**
  - **E.g., Red Sea**
- **"Rift-Drift" transition**
- **Rift-drift transition may be marked by a "breakup unconformity"**
  - **If rift associated with subaerial relief at onset of drifting**

Basin Classification

- **Passive Margins**

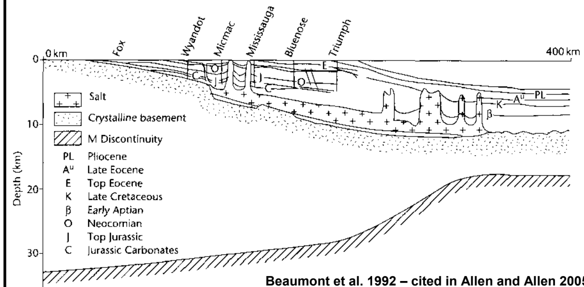


Continental Crust **Transitional Crust** **Oceanic Crust**

Basin Classification

- **Passive Margins**
  - **Strongly attenuated continental crust**
  - **Stretched over distances of 50-500 km**
  - **Overlain by seaward-thickening sediment prisms**
    - **Typically shallow-marine deposits**
  - **Sometimes referred to as "Atlantic-type margins" or "continental rises and terraces" (Boggs)**

Scotian Shelf



Beaumont et al. 1992 – cited in Allen and Allen 2005

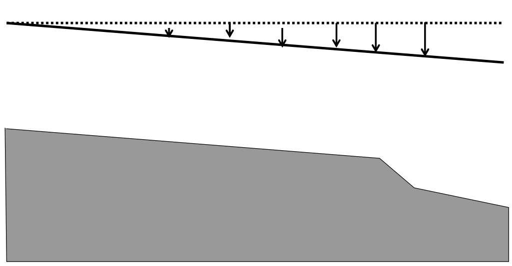
Basin Classification

- **Passive Margins**
  - **Various subsidence mechanisms:**
    - **Cooling (thermal contraction) following lithospheric thinning**
      - **Main mechanism**
    - **Phase changes in lower crust/mantle (gabbro to eclogite)**
      - **Not known if this process can be widespread enough**
    - **Sediment loading**
      - **Adds to other effects**

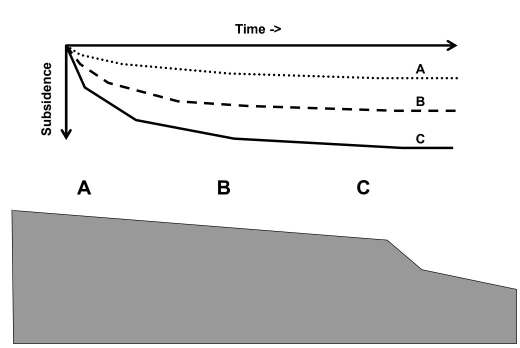
Basin Classification

- **Passive Margins**
  - **Subsidence variable in space and time**
    - **Subsidence rate increases in offshore direction**
    - **Subsidence rate decreases with time for all parts of the profile**

Total Subsidence



Subsidence as a Function of Time



Basin Classification

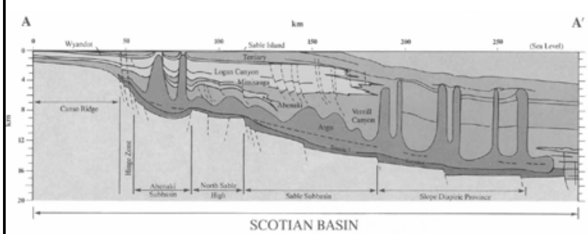
- **Passive Margins**
  - **Morphology characterized by shelf, slope and continental rise**
  - **Shelf margin builds out with time**
  - **Shelf sediments can be clastic or carbonate**
  - **Water depth stays relatively constant on shelf**
    - **Abundant sediment supply**

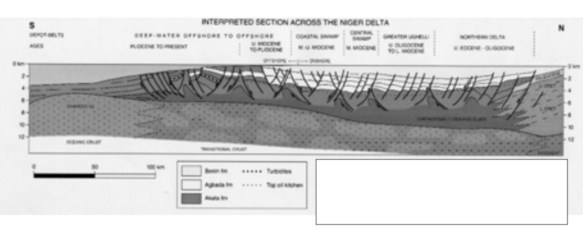
Basin Classification

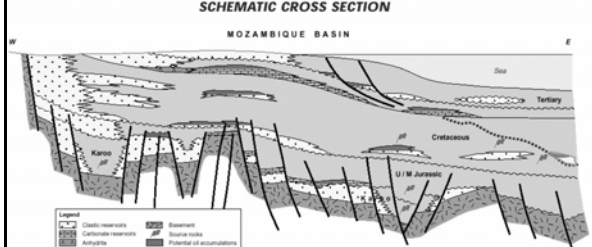
- **Passive Margins**
  - **Slope/rise – material shed from continental shelf during lowstands (clastic systems)**
  - **Aprons/fans deposited along slope/rise**
  - **Also pelagic sediments, contourites, etc.**

Basin Classification

- **Gravity-driven deformation common in drift-phase sediments**
  - **Listric growth faults, salt tectonics, mud diapirs, etc.**

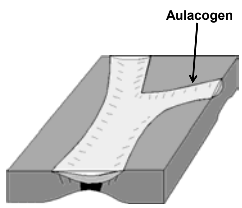


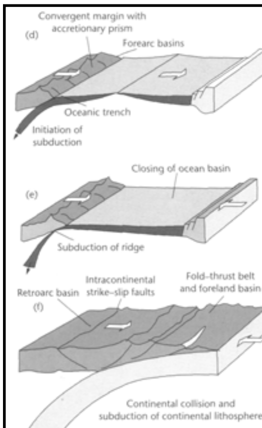




Basin Classification

- **Aulacogens**
  - **"Failed rifts"**
  - **Occur at high angle to continental margin**
  - **Fill: non-marine to deep marine**
  - **Example: Reelfoot Rift (Mississippi valley)**

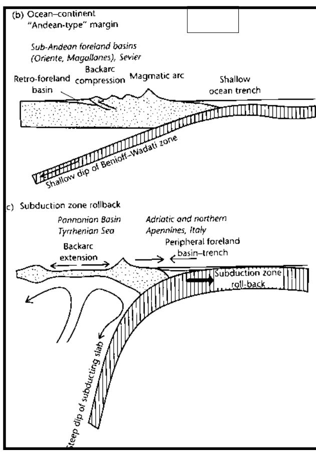




Allen and Allen, 2005

<u>Convergent Plate Boundaries</u>

Subduction of oceanic plate (d) may lead to closing of ocean basin (e) and ultimately to continental collision (f)



<u>Convergent Plate Boundaries</u>

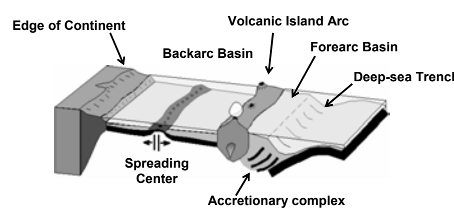
Age of oceanic crust affects angle at which it is subducted

Young crust (top) – shallow angle subduction, compression behind arc

Old crust (bottom) – steep angle subduction, "roll-back", extension behind arc

Basin Classification

- **Arc-related basins**

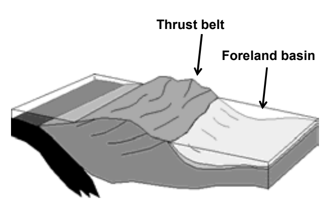


Basin Classification

- **Arc-related basins**
  - **Forearc and backarc basins dominated by sediment derived from arc**
    - **Immature clastics**
    - **Backarc basin may also have component derived from continent**
  - **Deep-sea trench has sediments derived from arc and sediments scraped off subducting oceanic crust**
    - **"Melange"**

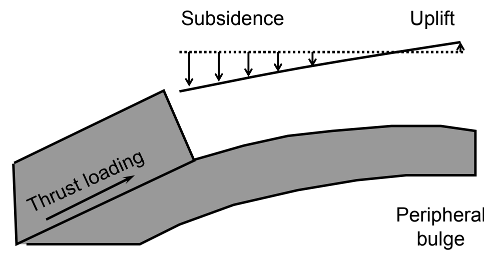
Basin Classification

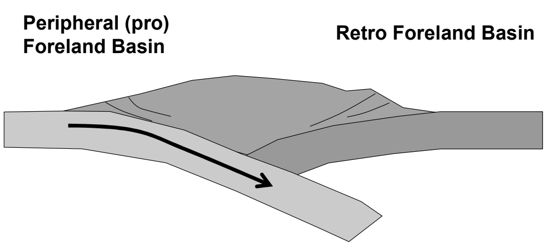
- **Foreland basins**

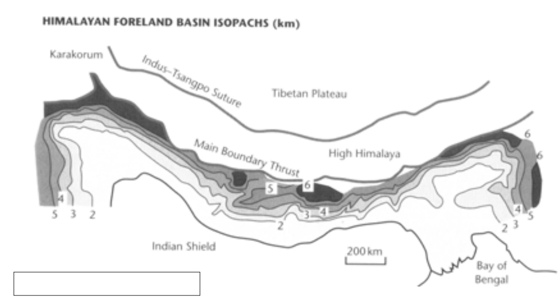


Basin Classification

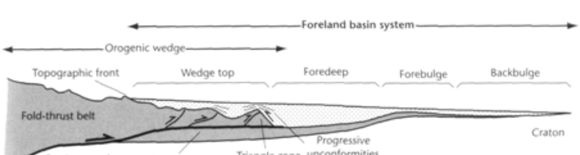
- **Foreland basins**
  - **Crustal loading of thrust sheets causes subsidence**
  - **May face towards or away from continental interior**
  - **Ocean-continent or continent-continent collision**
  - **Rate of subsidence greatest adjacent to thrust loading**







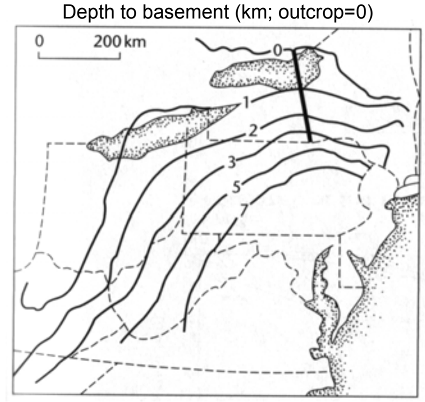
Himalayan peripheral foreland basin



Decelles and Giles, 1996

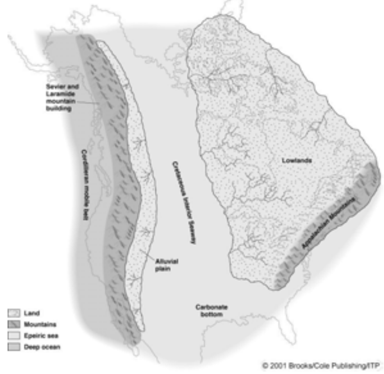
Retro foreland basins

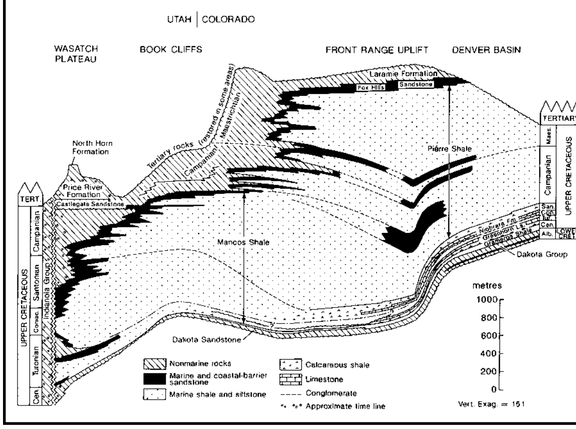
Depth to basement (km; outcrop=0)

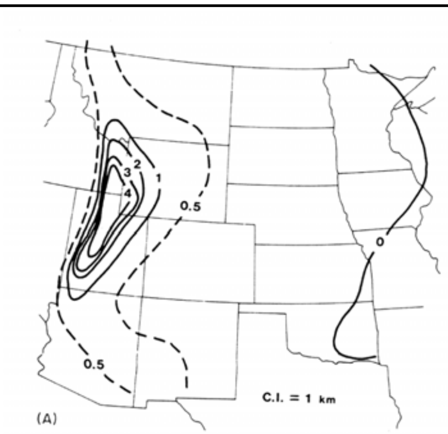


Turcotte and Schubert, 1982

Late Cretaceous







Basin Classification

- Foreland basins
  - Generally clastic – high sediment input from adjacent uplifts
    - "Clastic wedges"
      - Date thrusting
    - Carbonates in some settings
  - Marine or non-marine fill
    - Turbidites, pelagic, deltaic, shoreface/shelf, fluvial

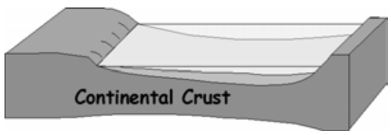
Basin Classification

- Foreland basins
  - Basin fill adjacent to thrusting typically gets caught up in deformation

Cretaceous Clastics, Alberta

Basin Classification

- Intracratonic Basins

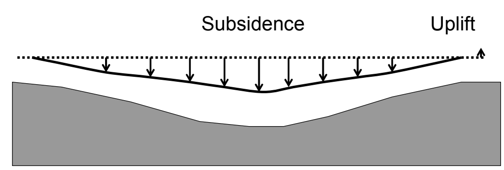


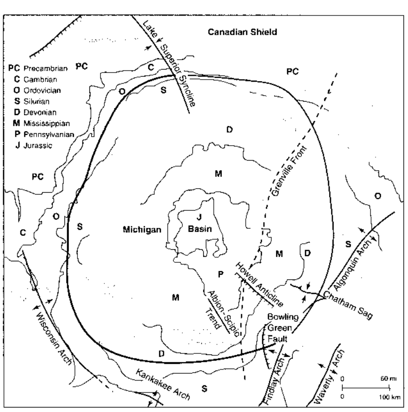
Basin Classification

- Intracratonic Basins
  - "Interior Basins"
  - Semi-circular to ovate downwarps
  - Within continental interiors
    - Otherwise stable cratonic areas
    - Away from plate boundaries

Basin Classification

- Intracratonic Basins
  - Causes of subsidence?
    - Underlying rifts, large-scale fault blocks
    - Cooling after intrusion of dense material
    - Mantle "cold" spots (downwelling)
    - Phase changes
  - Subsidence greatest towards center of basin



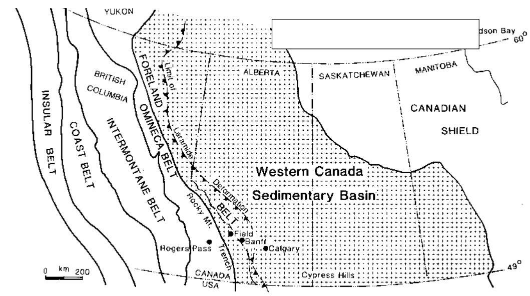


Basin Classification

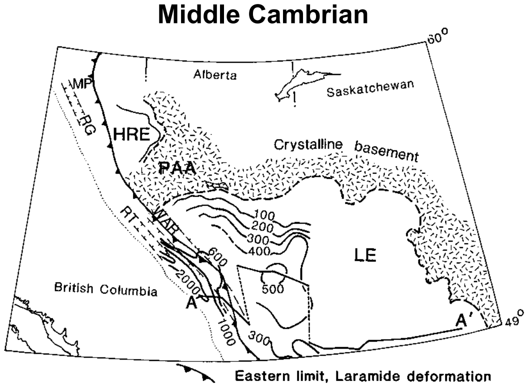
- Intracratonic Basins
  - Sedimentary fill terrestrial or marine
    - Carbonates, clastics, evaporites

Basin Classification

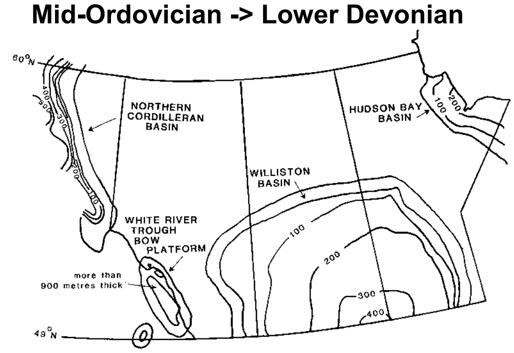
- **Other basins, e.g. basis associated with wrench faulting, not discussed here (time constaints)**
- **Some basins have had multiple-phase history**
  - **Sometimes related to reactivation because of changes in plate tectonic setting**
  - **E.g., Western Canada Sedimentary Basin**



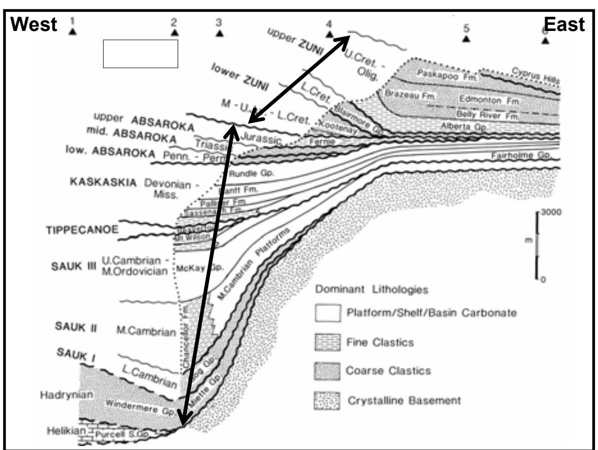
Middle Cambrian

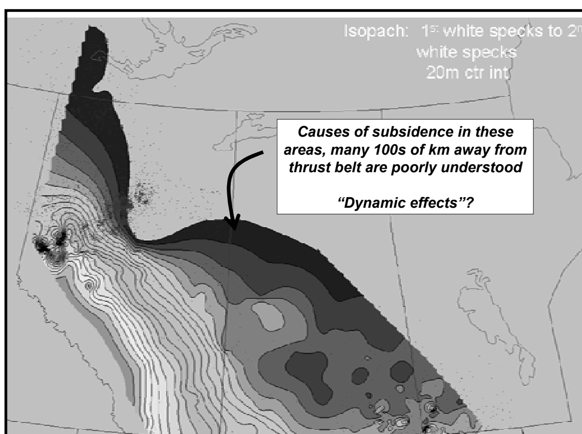


Mid-Ordovician -> Lower Devonian



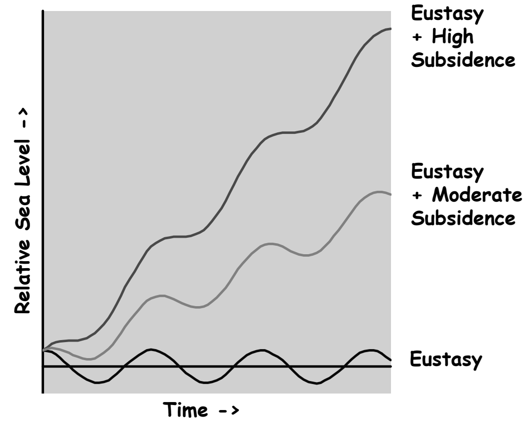
DISTRIBUTION AND THICKNESS OF TIPPECANOE SEQUENCE

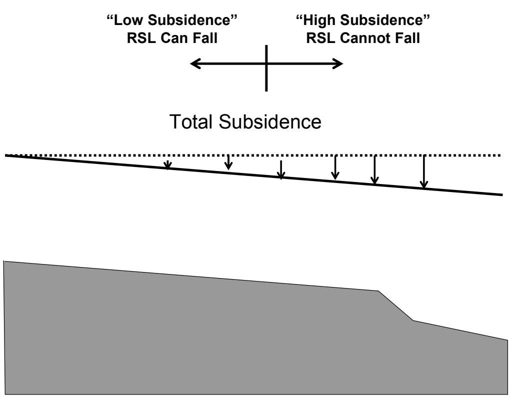




Basins and Sequence Stratigraphy

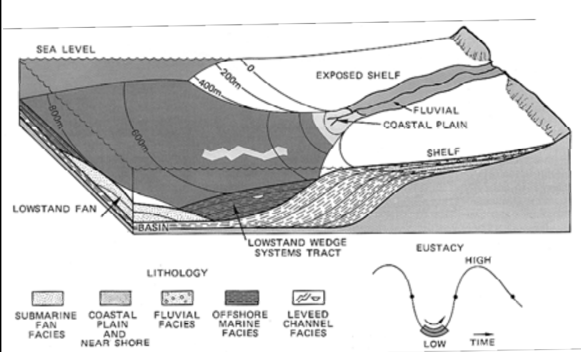
- **Patterns and rates of subsidence and sediment supply can be strongly influenced by tectonic processes that are responsible for forming some basins**
- **Temporal and spatial changes in these factors can significantly affect sequence development in those basins**





Basins and Sequence Stratigraphy

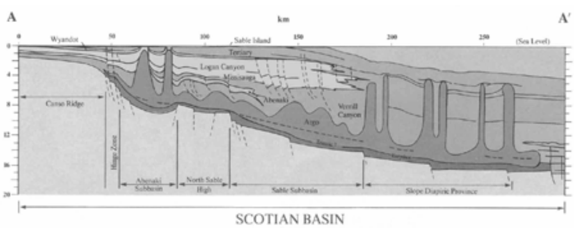
- **Towards shelf margin – rate of subsidence is always greater than rate of eustatic fall**
  - **No fall of relative sea level**
- **Further landward – rate of subsidence is less than rate of eustatic fall**
  - **Fall of relative sea level possible**
  - **Incised valleys can form**
- **Area covered by each zone will change with time, basin to basin**

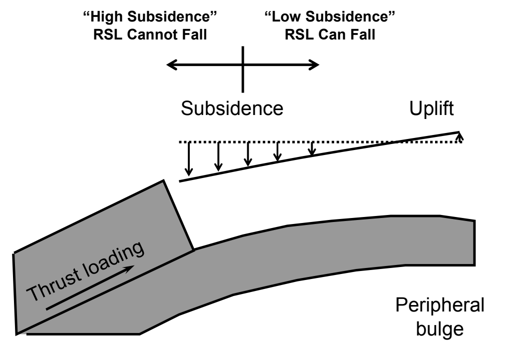


Fluvial incision is greatest near landward edge of shelf

Basins and Sequence Stratigraphy

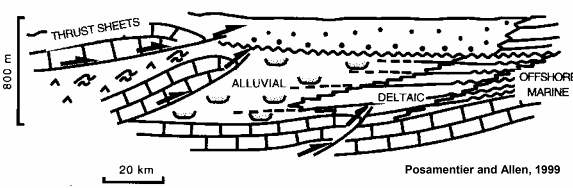
- **When a discrete shelf margin is present, shelf margin sediments may be thick even in the absence of rapid thermal/tectonic subsidence**
  - **Faulting, compaction, diapirism cause localized subsidence**





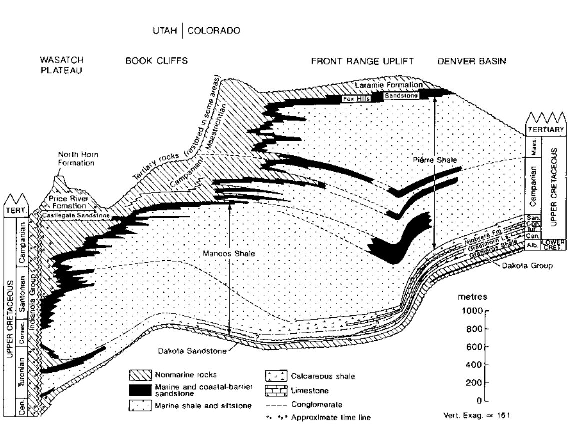
Basins and Sequence Stratigraphy

- Towards thrust belt – rate of subsidence is always greater than rate of eustatic fall
  - No fall of relative sea level
  - Favours fluvial accomodation/deposition towards thrust belt
- Further basinward – rate of subsidence is less than rate of eustatic fall
  - Fall of relative sea level possible
- Area covered by each zone will change with time, basin to basin



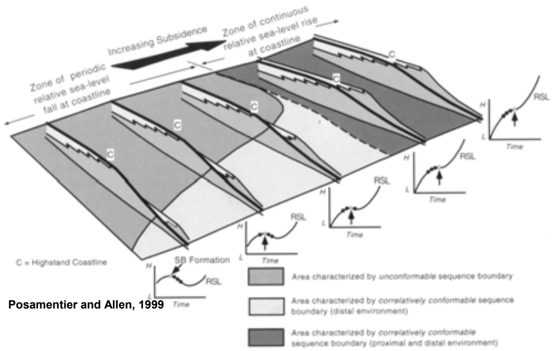
Dignes (Miocene) Foreland Basin, SE France

Thickest preserved fluvial ("alluvial") sediments adjacent to thrust belt



Basins and Sequence Stratigraphy

- Variations in subsidence along strike in a basin can also cause variations in sequence development



Basins and Sequence Stratigraphy

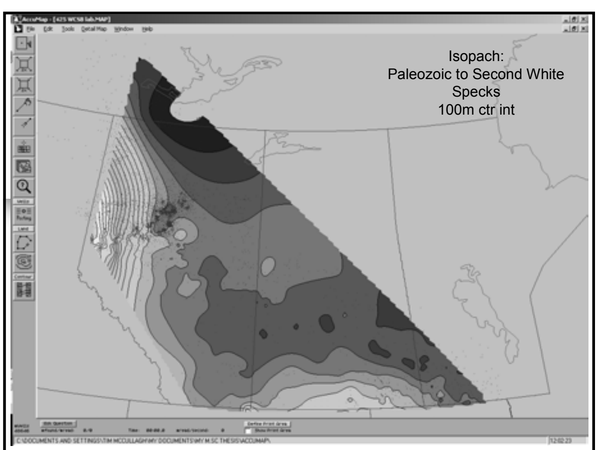
- **Uplift along basin margins can cause variations in sediment supply**
  - **Uplift due to thrusting and other processes**
  - **Erosion of highlands**
- **Variations in sediment supply can generate "cycles" whose development has little/nothing to do with eustatic changes in sea level**
  - **Especially in basins dominated by fluvial deposition**

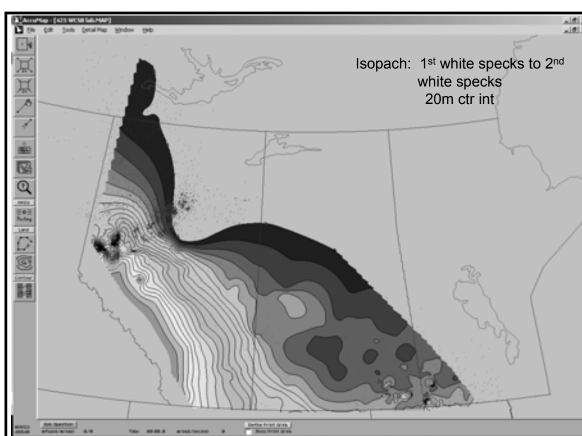
Basins and Sequence Stratigraphy

- **Development of a shelf profile most common on passive margins**
  - **Allows lowstand clastic deposits (submarine fans) to form**
- **Foreland basins typically have a ramp profile**
  - **Absence of deep-water deposits (i.e., lowstand fans)**

Basins and Sequence Stratigraphy

- **Subsidence rates for a given basin may be determined using a variety of techniques**
  - **E.g., "backstripping"**
- **Subsidence mechanisms/patterns can be derived from examining sedimentary record**
  - **Thick sediment accumulations correspond to rapid subsidence and/or high sediment supply**





Summary

- Sedimentary basins are repositories for sediment that are formed by crustal subsidence relative to surrounding areas
- Several different mechanisms can produce subsidence, but they can be grouped into two main categories:
  - Isostacy
  - Loading

Summary

- Sedimentary basins are found in many different tectonic settings
  - "Wilson Cycle" a useful concept for classifying basins
    - Opening and closing of ocean basins
    - Not all basins fit into this conceptual framework

Summary

- Divergent plate boundaries – rift/drift transitions
  - Not all rifts lead to the opening of ocean basins
  - Passive margins have highest subsidence that increases seawards
    - Subsidence primarily due to cooling

Summary

- Foreland basins – subsidence due to loading by thrust sheets
  - Highest subsidence closest to thrust sheets
- Intracratonic basins – away from plate boundaries, causes of subsidence poorly understood
- Basins can have complex histories

Summary

- Tectonic and other factors that cause subsidence and influence sediment supply can have a significant impact on sequence development
  - Likely to vary from basin to basin, and over time within any given basin