Stratigraphic Evolution and Reservoir Quality in a Neogene Accretionary Forearc Setting: Eel River Basin of Coastal Northwestern California*

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Abstract

Studies of modern and ancient subduction zones and accretionary forearc settings can shed light into regional tectonic histories, as well as evaluate petroleum reservoir potential within these settings. Published models of trench-slope (accretionary forearc) basin evolution describe a thick (>2 km) succession of coarsening-upward sedimentary fill deposited on top of an accretionary basement. The southern Eel River basin in the vicinity of coastal northwestern California is an excellent example of an ancient trench-slope basin. Its outcrops and subsurface data provide a wonderful opportunity to validate/update the aforementioned models, as well as document the petroleum reservoir potential within a Neogene accretionary forearc basin.

The Eel River basin developed near the base of an inner trench slope (inboard of the Cascadia subduction zone) in the early Miocene. The tectonic development and infilling of the Eel River basin are recorded in its stratigraphy. Earliest basin deposits, the lower-middle bathyal Bear River beds, are comprised of isolated hemi-pelagic siliceous mudstones and calcareously-cemented sandstones. These beds are areally confined and are quite rare in basin margin outcrops; this observation reflects a structurally confined or terraced depositional environment on the lower trench slope. After deposition of the Bear River beds, there was an apparent basin reconfiguration. This allowed for subsequent, more areally extensive Wildcat Group deposition which “healed” older structural ridges. As in other California basins, this late Miocene-Pleistocene sedimentary succession is thick and mostly conformable. The Wildcat Group records generally shoaling basin conditions, from bathyal debris-flow deposits and turbidites to fluvial deposits. These deposits represent an upward-thickening trend.

XRD analyses performed on Wildcat Group turbidite sandstones (from conventional core and outcrop) reveal a relatively high clay mineral content (19-28%). SEM analyses reveal extensive bioturbation, and demonstrate that clays are authigenic as well as detrital in origin. Detrital clays were largely entrained into turbidity currents on the muddy slope. Reservoir quality is especially diminished by

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the presence of authigenic clay minerals, which formed due to alteration of constituent plagioclase feldspars and diagenetic processes. Horizontal permeability values range from <1 md in silty turbidites up to 36 md in thickest turbidite sands.

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Stratigraphic evolution and reservoir quality in a Neogene accretionary forearc setting: Eel River basin of coastal northwestern California

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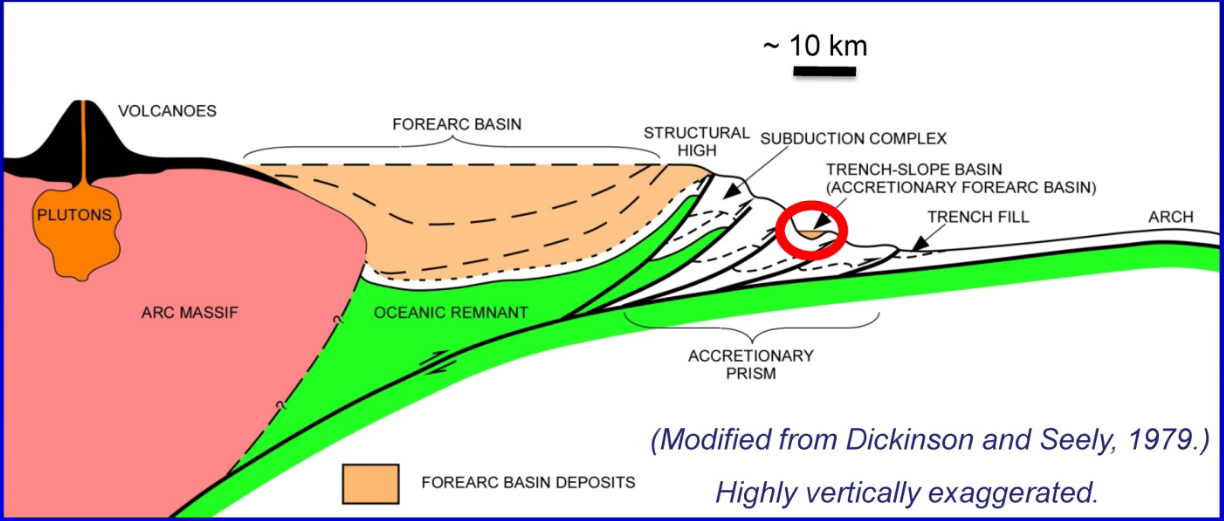
Goals of this presentation:

- Overview of trench-slope (accretionary forearc) basin models
  - Geometry and associated structures
  - Stratigraphic trends
  - Subsidence and uplift

- Detailed case study: onshore Eel River basin, CA
  - Stratigraphy; key unconformities; subsidence vs. tectonic uplift; eustatic signatures (?)
  - *Are the Eel River basin data in agreement with the published models?*
  - *What makes the Eel River basin unique?*

- Reservoirs of the onshore Eel River basin
  - *What might these reservoirs and the source rocks suggest about hydrocarbon recovery and petroleum systems in accretionary forearc regions?*

1. Trench-slope basin models

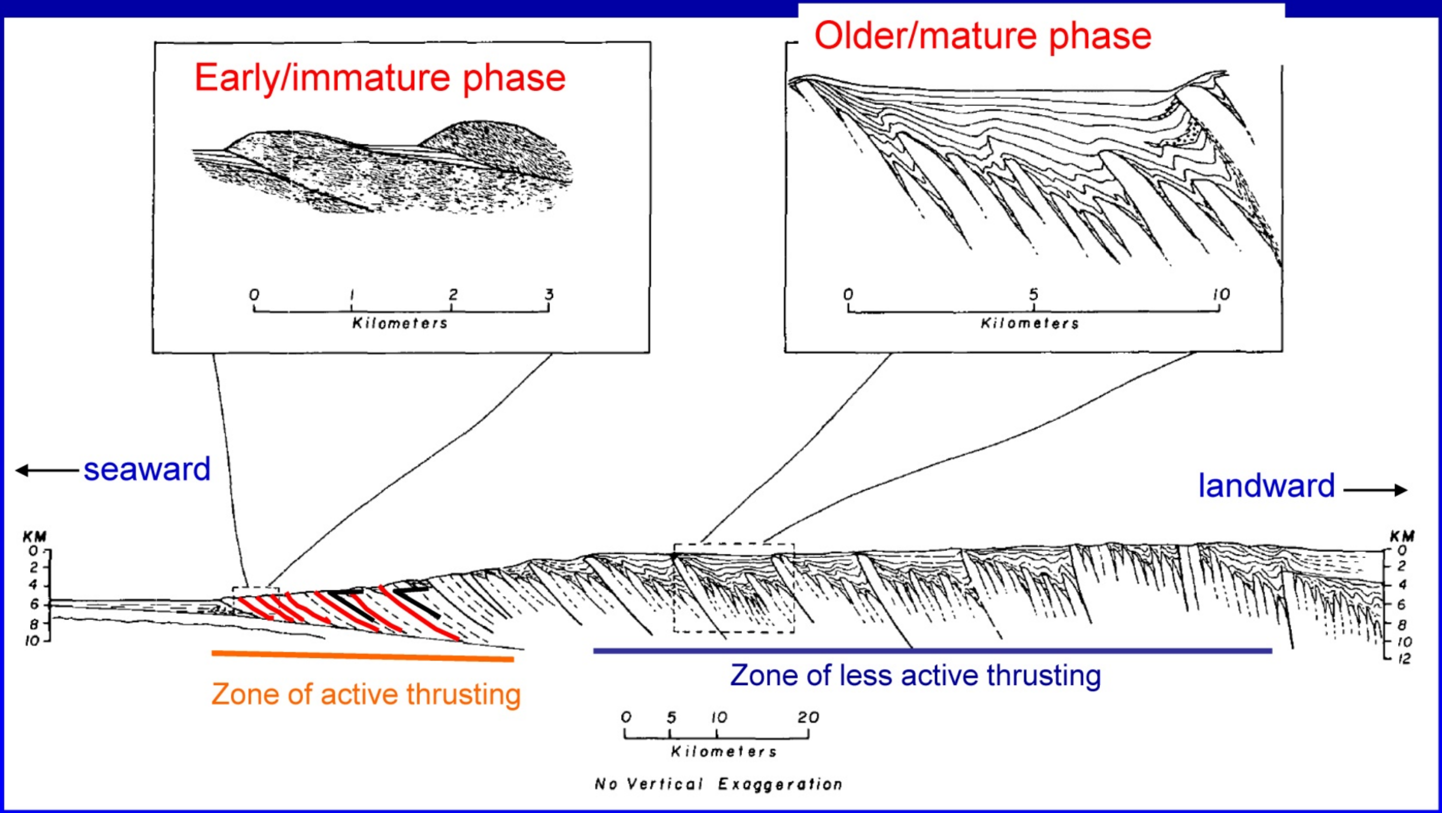


- These basins form on top of the accretionary wedge
- Active thrusting (oceanward-vergent) and fault-related folding creates structural ridges
- Onlapping and asymmetric fill in small lower-slope basins (active thrust zone)
- Continued accretion of trench sediments, and faulting: uplift and rotation; older strata dip landward
- Sedimentation buries inactive, older thrusts higher on the slope. With time and tectonics, smaller slope basins "coalesce" into a larger slope basin.

(Moore and Karig, 1976; Laursen and Normark, 2003; Underwood and Moore, 1995; Underwood et al., 2003)

Notes by Presenter: Also called terraced forearcs or accretionary forearcs. Highly idealized cross-section of a subduction zone (Dickinson and Seeley, 1979). Note vertical exaggeration.

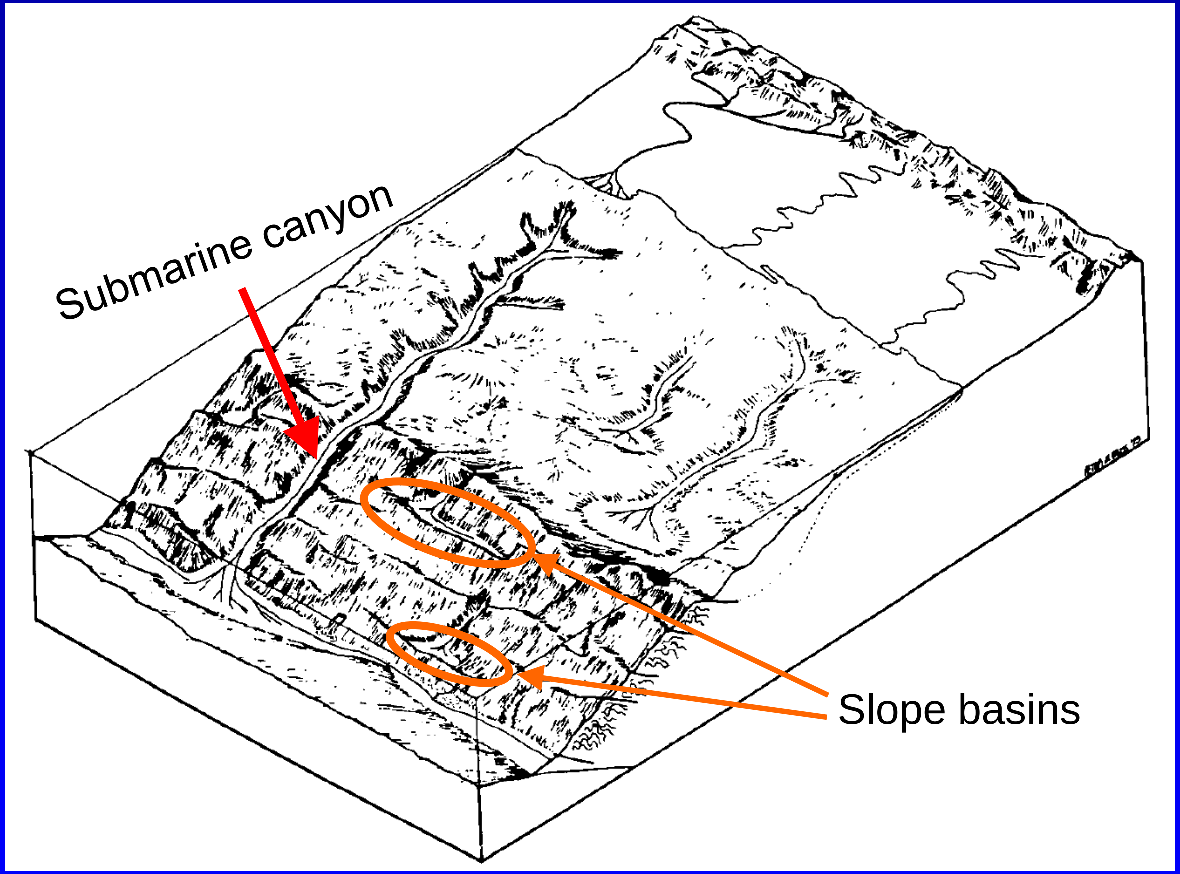
1. Trench-slope basin models



*(Modified from Moore and Karig, 1976. Based upon seismic profiles and field work on **Nias Island, Sunda arc, western Sumatra**.)*

Notes by Presenter: Nias seismic

1. Trench-slope basin models

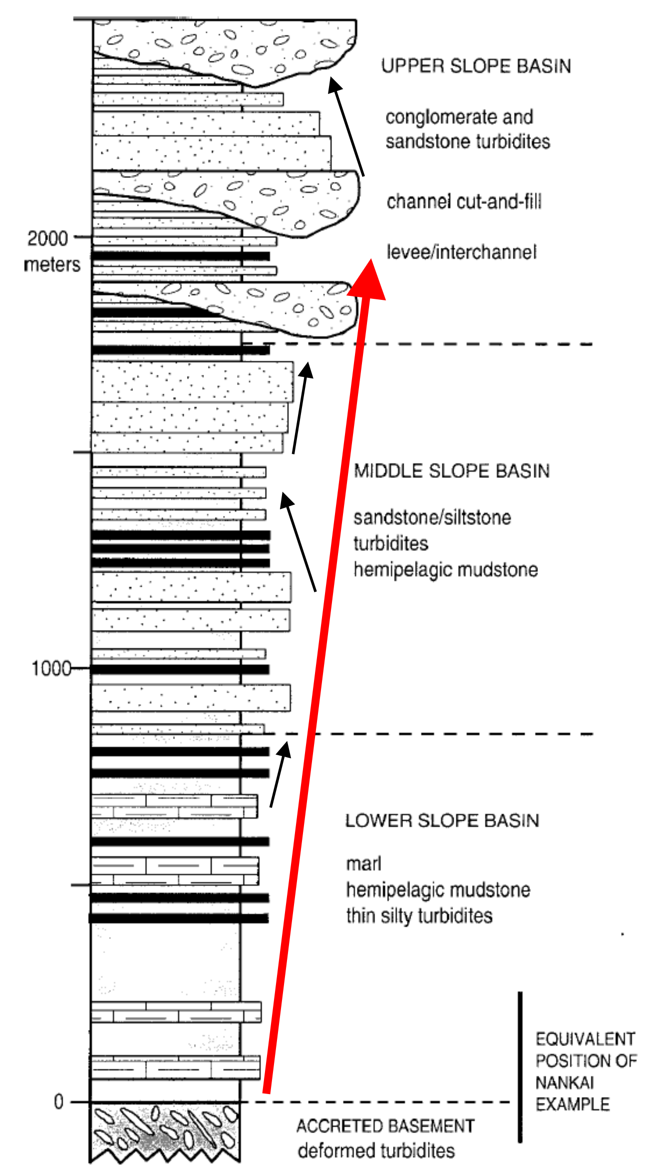


- Submarine canyons might form in transverse/tear fault zones
- Can be persistent features on the slope
- Canyons: an important clastic delivery system to slope basins
- In absence of canyons, slope sedimentation in “isolated” basins often dominated by hemi-pelagics and unconfined turbidity currents

(Modified from Underwood and Karig, 1980.)

1. Trench-slope basin models:

Stratigraphic trends



- Stratigraphic infill often > 2000 m thick
- Generally: coarsening- and thickening- and shallowing-upward stratigraphic successions
- Notable exceptions:
  - trench-slope basins in the **Nankai subduction zone** (fining-upward due to re-routing of sediment transport systems; subduction of seamounts)
  - Miocene **Akitio trench-slope basin (NZ)**

KEY CONSTRAINTS ON STRATIGRAPHIC INFILL: tectonics, sediment-delivery systems, eustasy

(Modified from Underwood et al., 2003.)

1. Trench-slope basin models:

Subsidence and uplift

(non-eustatic controls on accommodation)

<u>Subsidence drivers</u>

•Subduction erosion in forearc region (*e.g., Talara basin, Lima basin, Peru*)

•Tectonic loading (*in accretionary forearcs*)

•Sedimentary loading and compaction

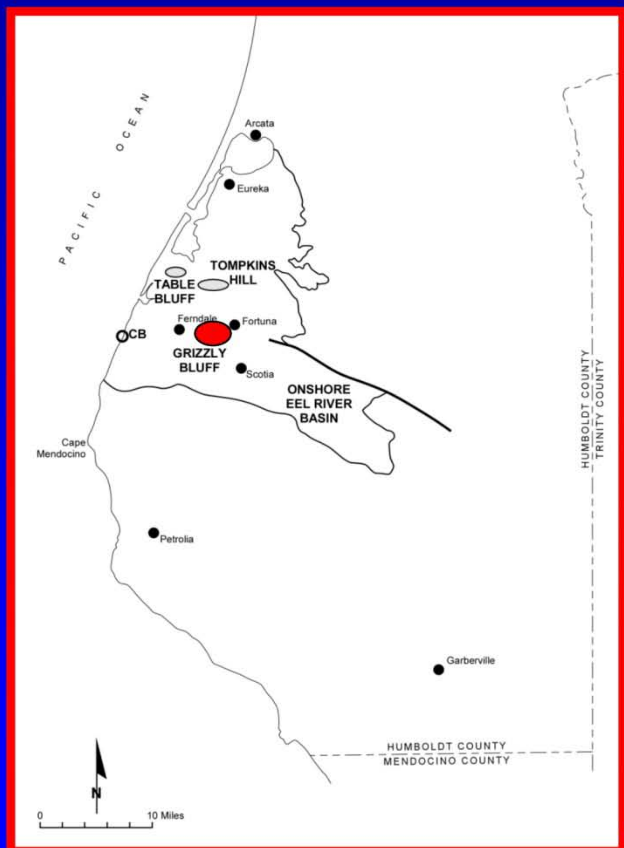
•Possibly, dynamic subsidence due to low-angle slab subduction (*sensu Gurnis, 1992*)

<u>Drivers of uplift</u>

•Accretion, and tectonic uplift (*thrusting in the accretionary prism*)

•Thermo-tectonic isostasy (*e.g., southern Cascadia*)

2. Onshore Eel River basin
California



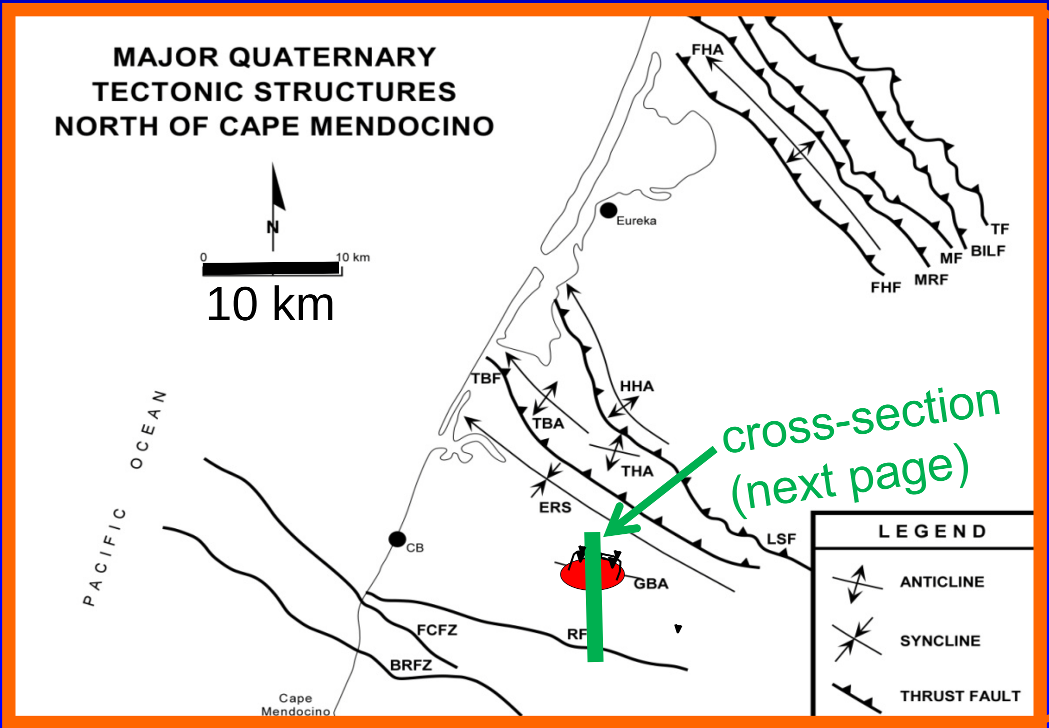
(Figure modified from Ogle, 1968.)

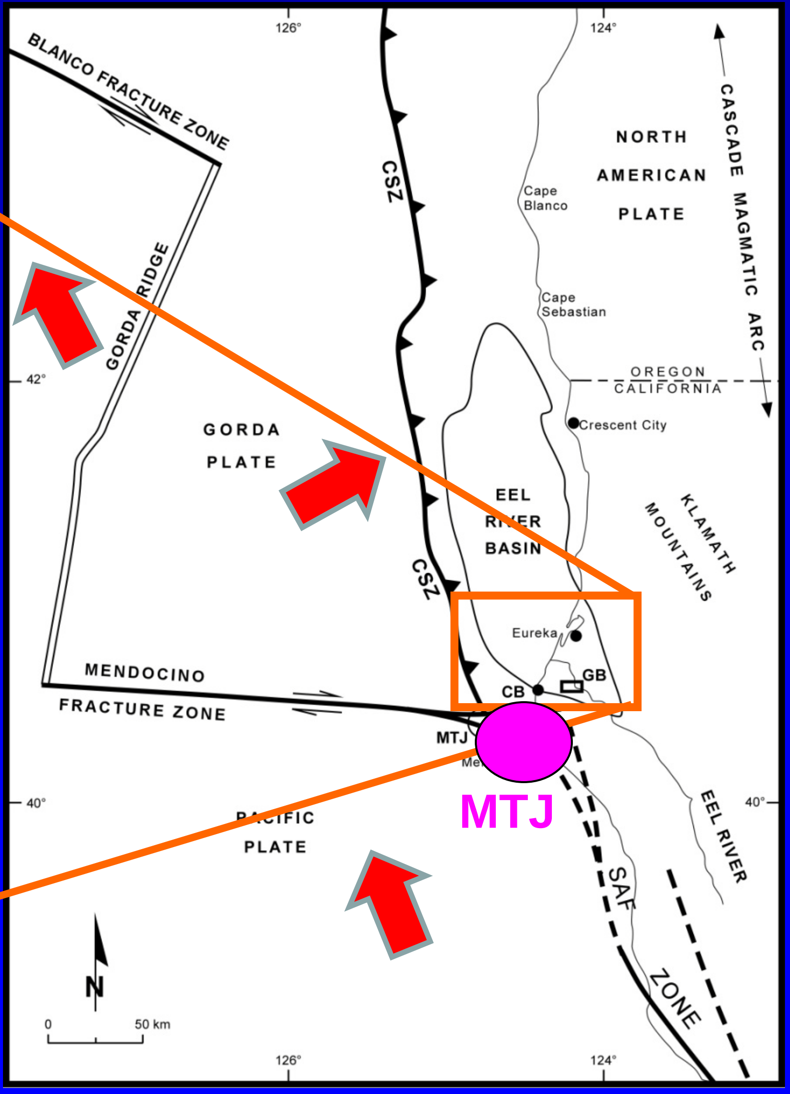
(Figure modified from Maher et al., 1975.)

Notes by Presenter: Note presence of Grizzly Bluff gas field (red) in onshore Eel River basin, the primary study area.

2. Onshore Eel River basin tectonic setting

•Big red arrows (right) indicate direction of principal plate motion.

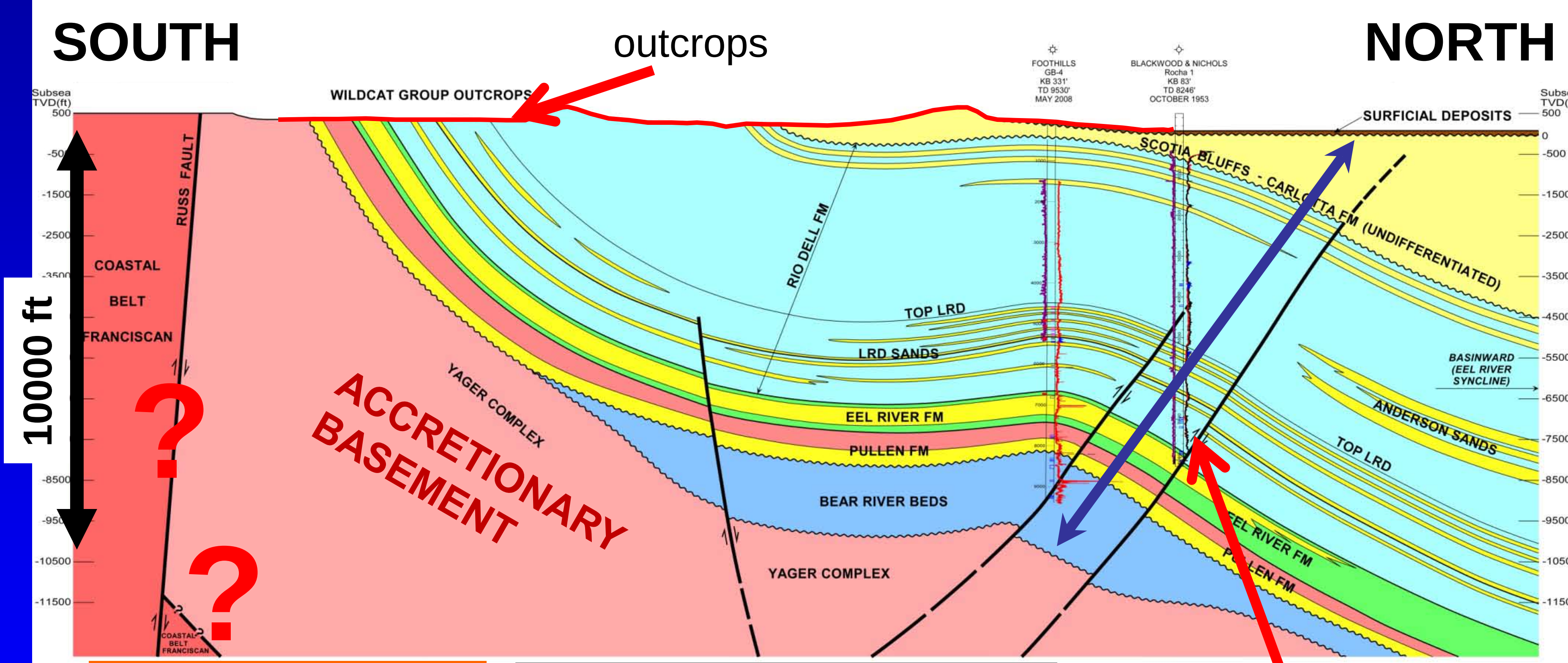


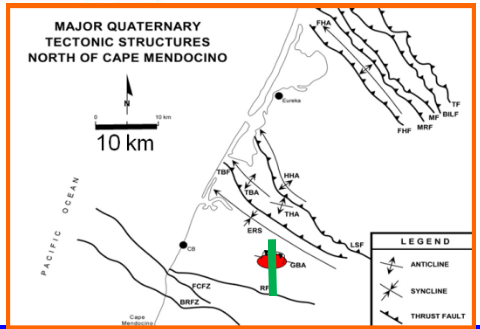


(Figures modified Carver, 1987; Clarke, 1992.)

2. Onshore Eel River basin

(southern margin)



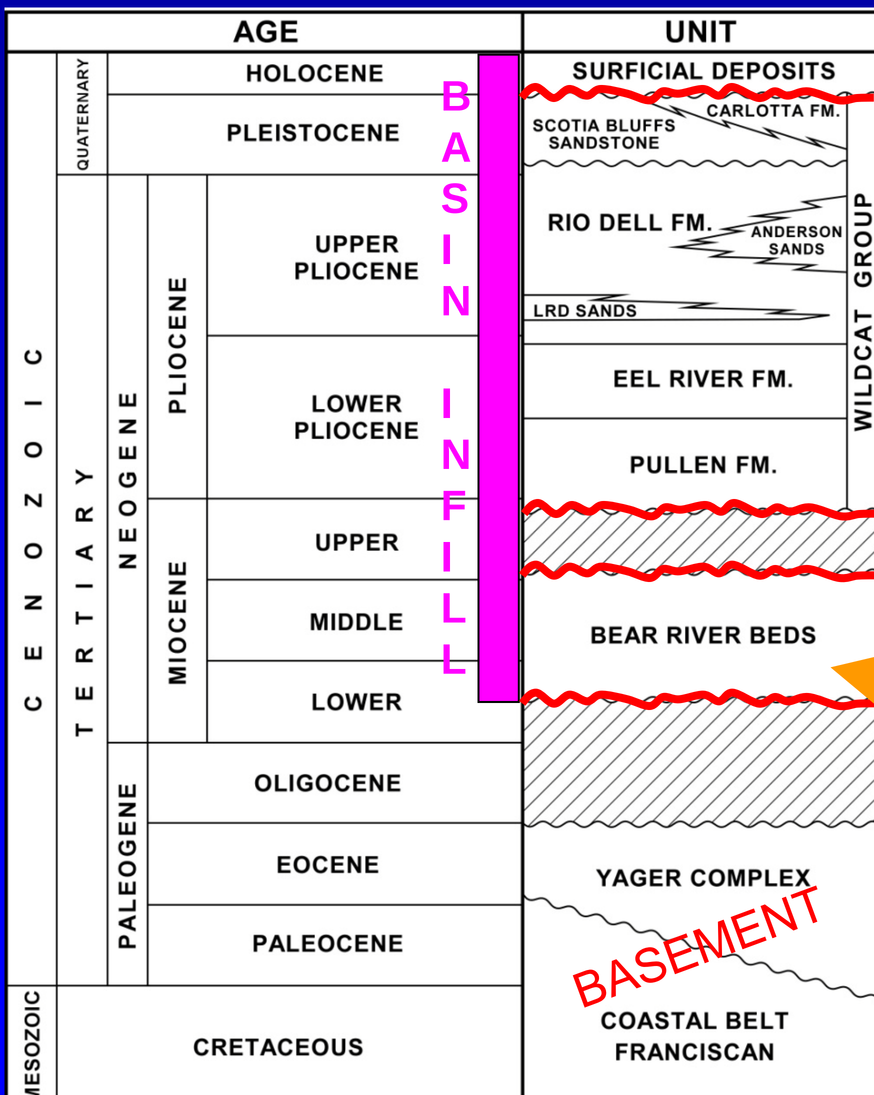


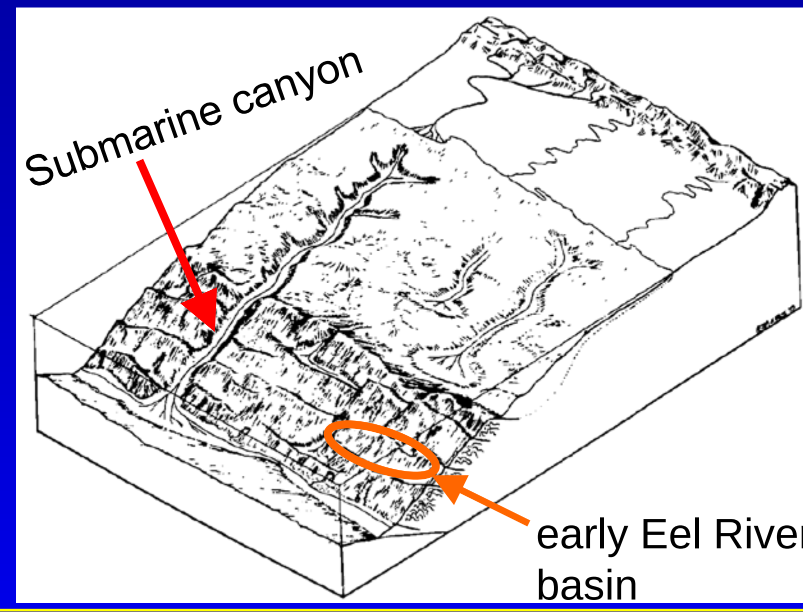
- Grizzly Bluff anticline cored by small, nascent northward-vergent thrusts
- Reactivation of minor Miocene normal faults?

well data
(Grizzly Bluff gas field)

2. Onshore Eel River basin

Stratigraphy: Bear River beds



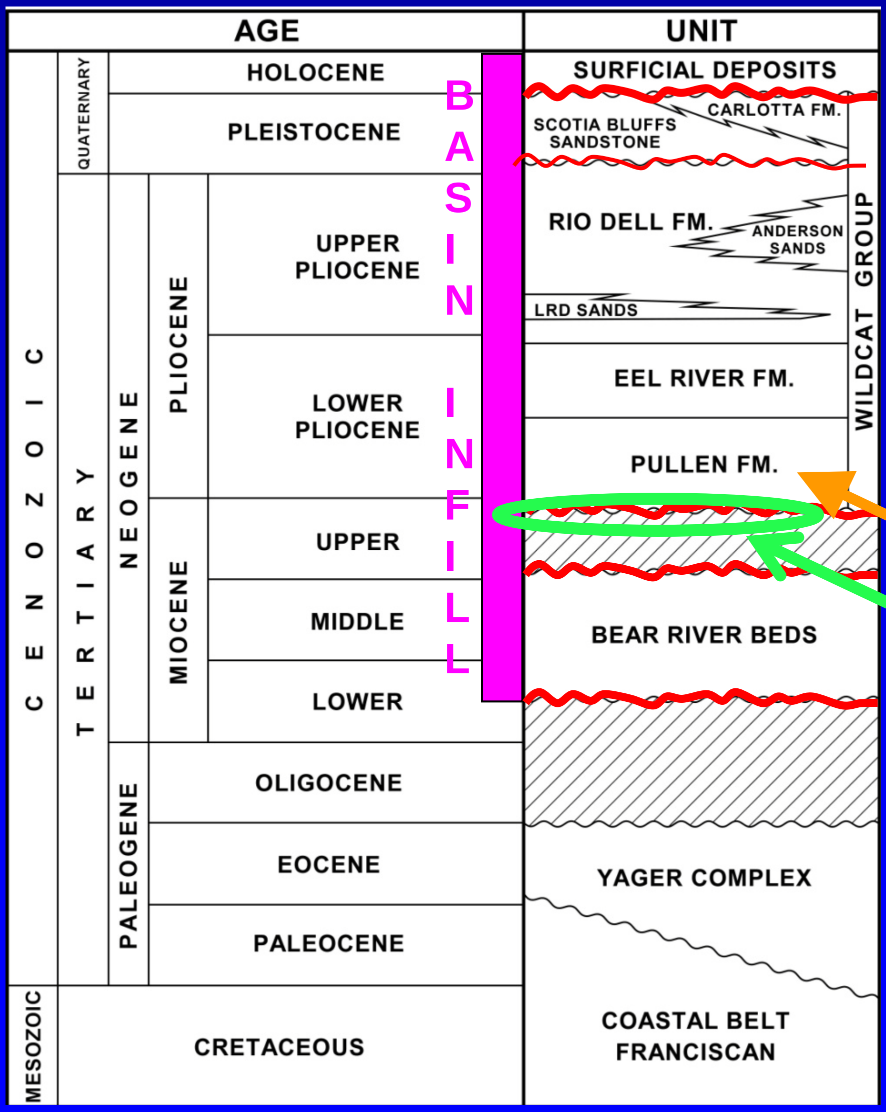


Bear River beds: earliest basin fill

- Contain lower bathyal benthic forams
- Pelagic and hemi-pelagic bio-siliceous mudstones; occasional thin-bedded turbidite sandstones
- Isolated outcrops
- Well logs suggest a high degree of faulting

2. Onshore Eel River basin

Stratigraphy: Pullen Fm.



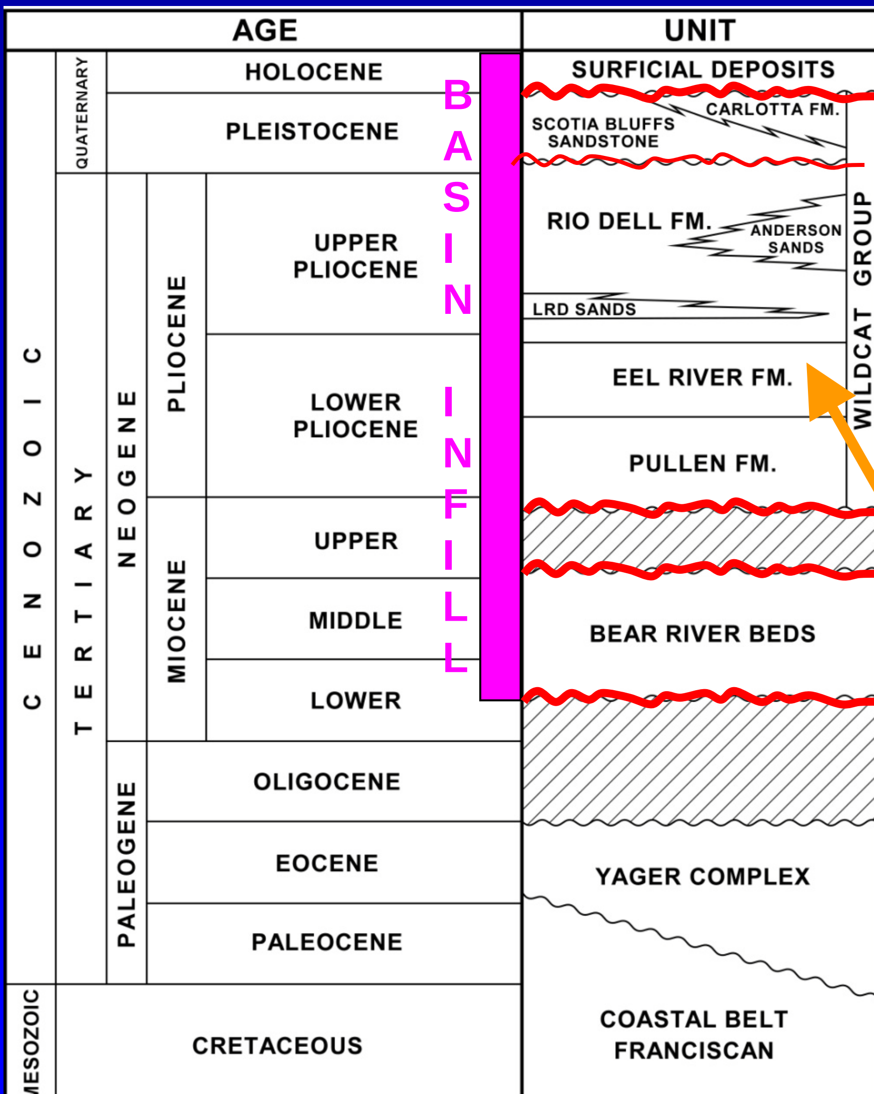
Basal Pullen debrite

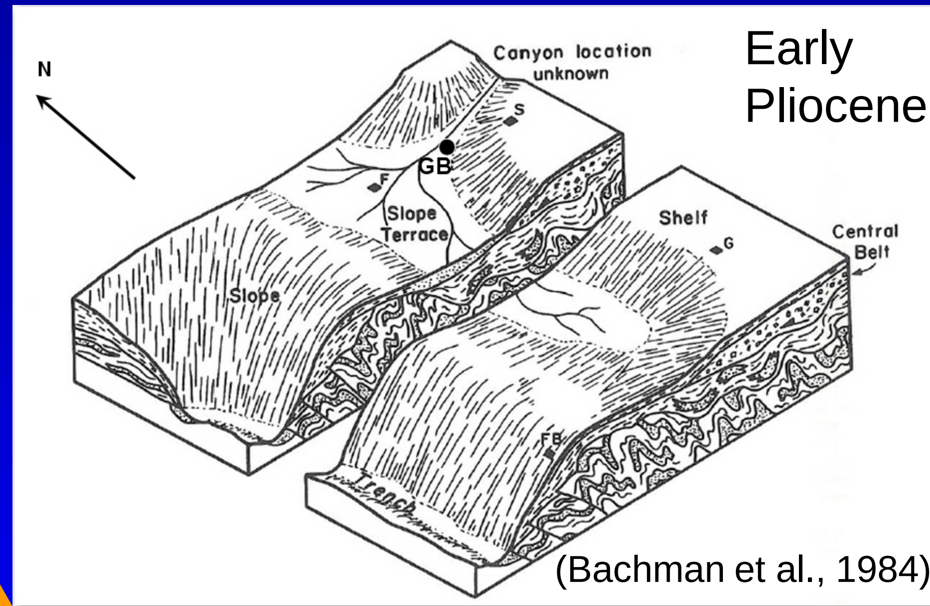
Pullen Formation

- Borehole image logs: **angular unconformity** between basal Pullen and underlying Bear River beds
- Coarse-grained basal debris-flow deposit, angular clasts: implies tectonic movement
- middle bathyal forams
- Upper Pullen: thin vf turbidite sands and light-gray mudstones (terrigenous influx)

2. Onshore Eel River basin

Stratigraphy: Eel River Fm.





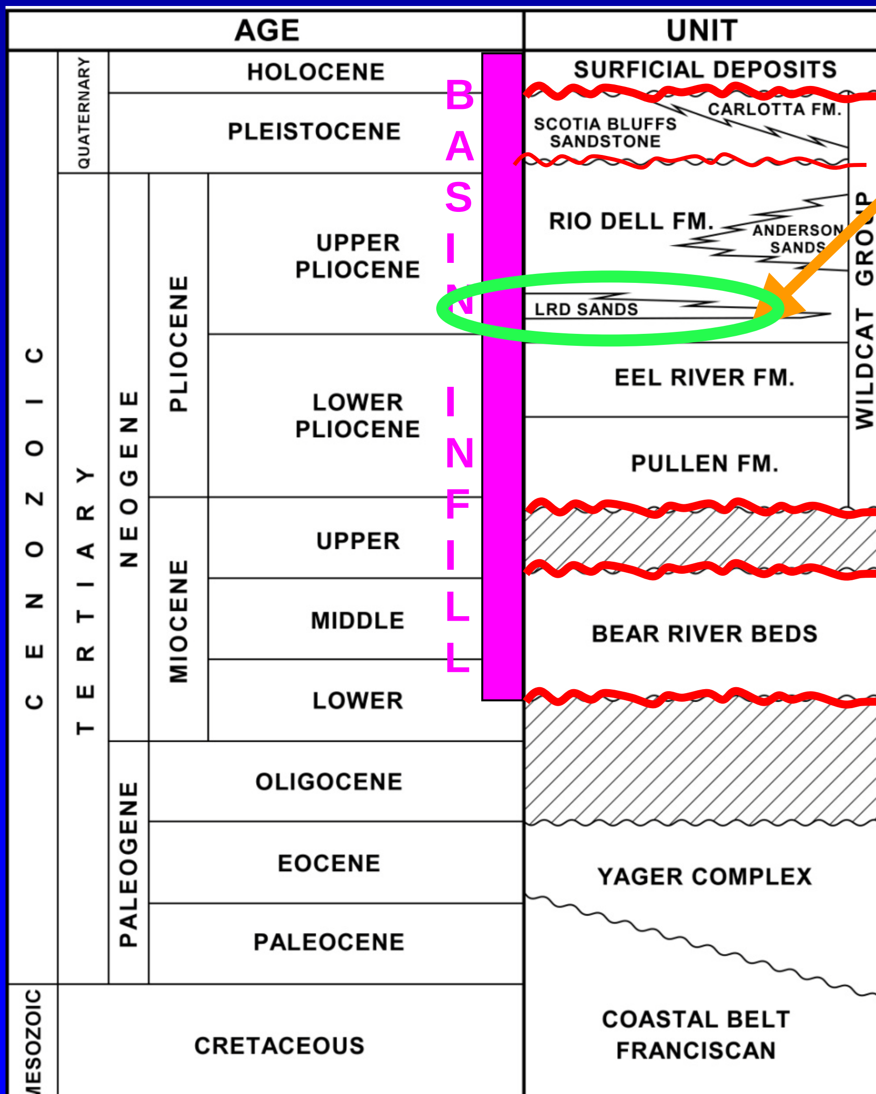
(Bachman et al., 1984)

Eel River Formation

- Mudstones, siltstones, and glauconite-rich, vf turbidite sands
- Middle bathyal forams
- XRD: 24% clay minerals

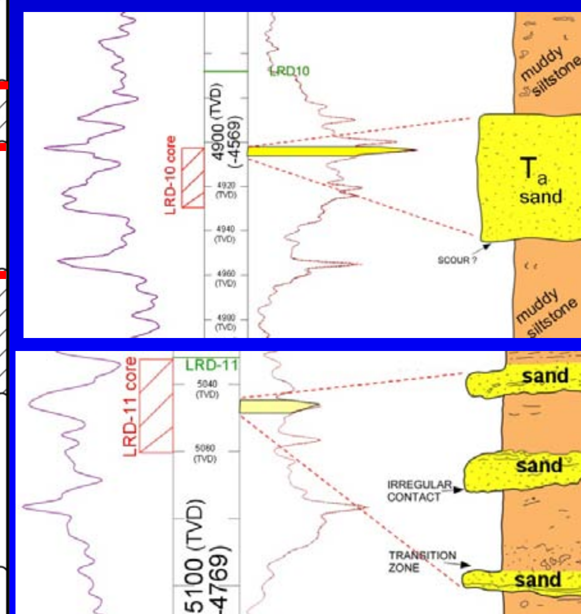
2. Onshore Eel River basin

Stratigraphy: lower Rio Dell Fm.



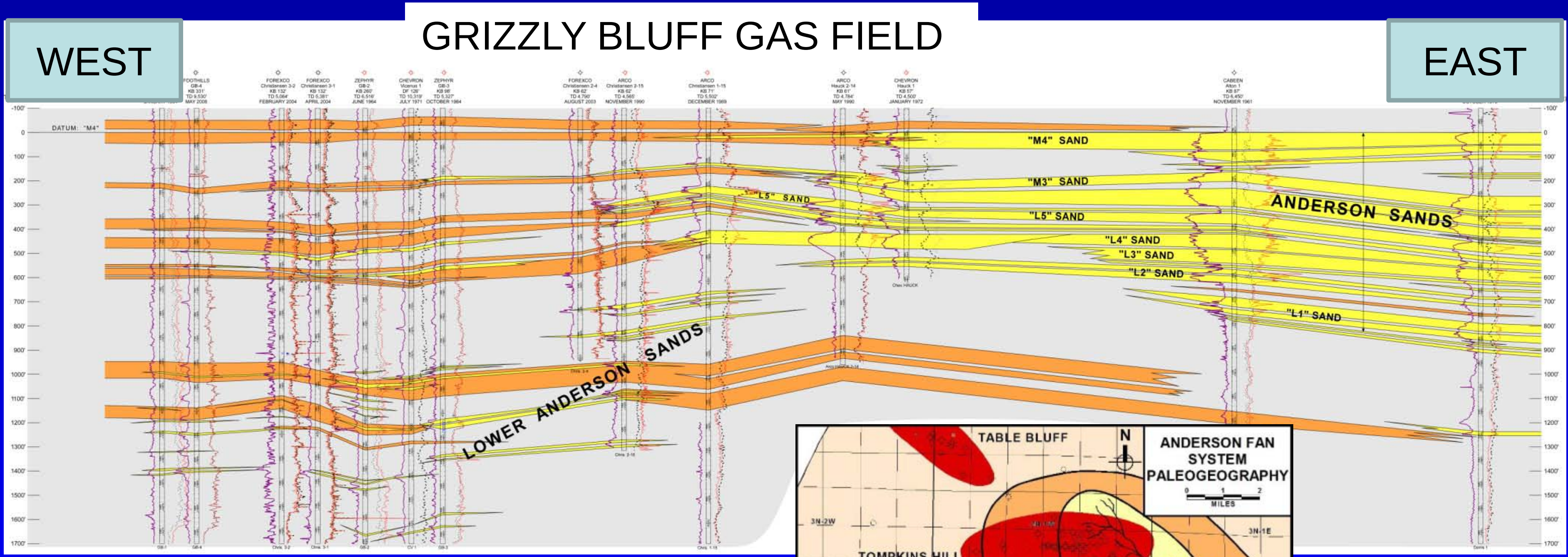
Lower Rio Dell Formation

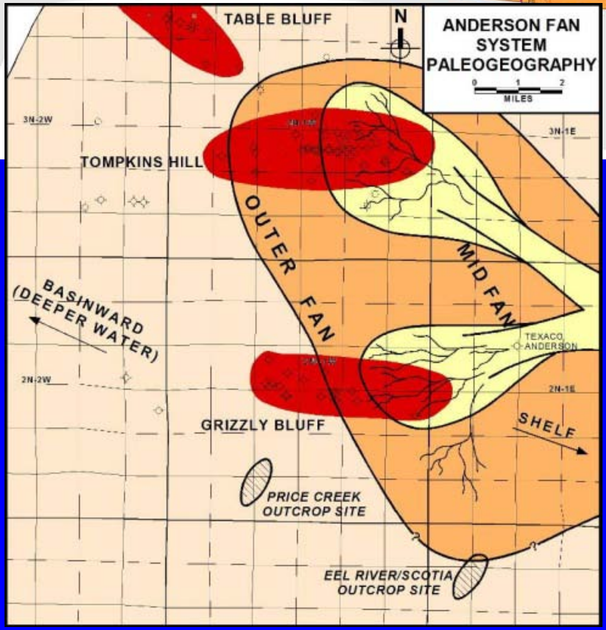
- upper bathyal benthic forams
- Mudstones; interbedded muddy silts and fine to very-fine turbidite sandstones
- Extensively bioturbated; low N:G
- XRD: Clay-rich sands (19-29%)



2. Onshore Eel River basin

Stratigraphy: Anderson sands (upper Rio Dell Fm.)



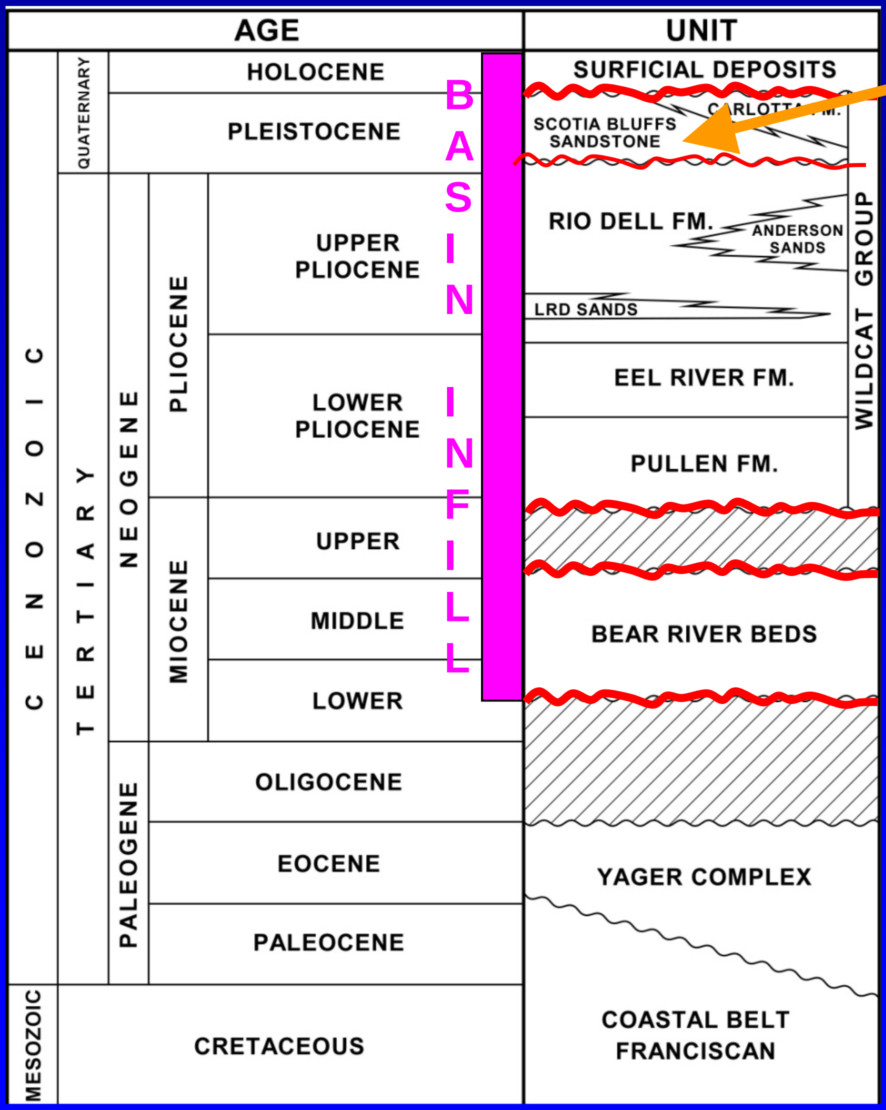


<u>Anderson submarine fan system:</u>

- West-northwestward-directed
- Documented in well logs and cross-sections
- Fine-vf-grained sands
- Higher N:G, Tmax than LRD sands
- Gas reservoirs at Grizzly Bluff

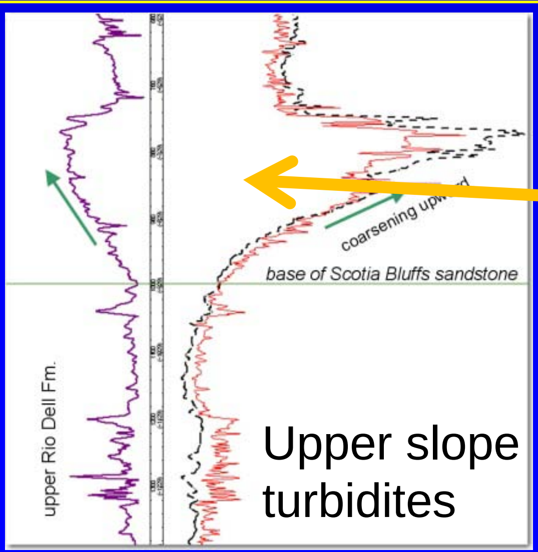
2. Onshore Eel River basin

Stratigraphy: Scotia Bluffs sandstone



Scotia Bluffs

- Fauna indicate neritic and littoral environments (continued shoaling)
- Fine- to medium-grained sand
- Prograding shelf-shoreline complex
- HCS indicates deposition in a wave-dominated coastline



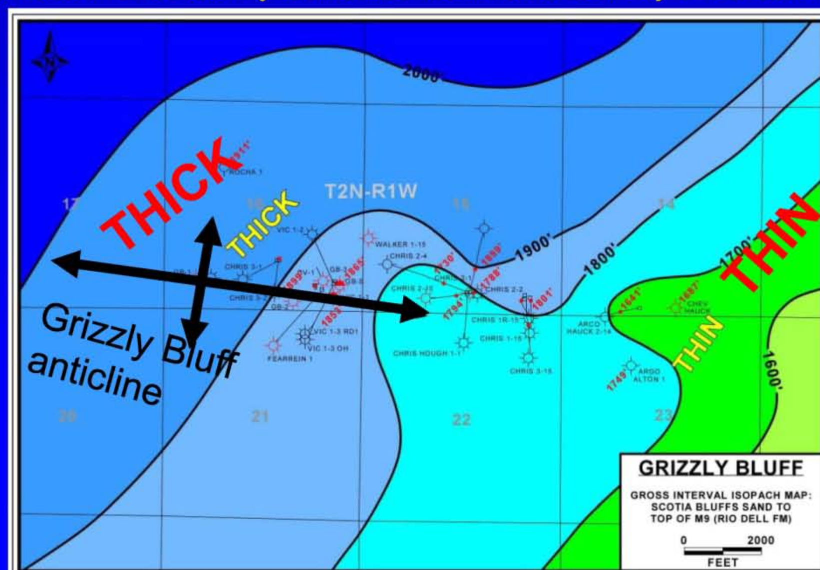
Scotia Bluffs Ss.

2. Onshore Eel River basin

"After" the Scotia Bluffs Ss:

- Non-marine (fluvial) units deposited, and then Recent Eel River deposits
- Gross interval isopach mapping, and a review of proprietary seismic data, indicates that north-south compressional features such as Grizzly Bluff anticline were not active until the late Pleistocene. (ALSO: tilted lower Pleistocene strata in outcrop) This is due to approach of the Mendocino triple junction.

- Hence, Mio-Pliocene turbidite deposition in the southern margin of the Eel River basin was not affected by structures such as Grizzly Bluff anticline

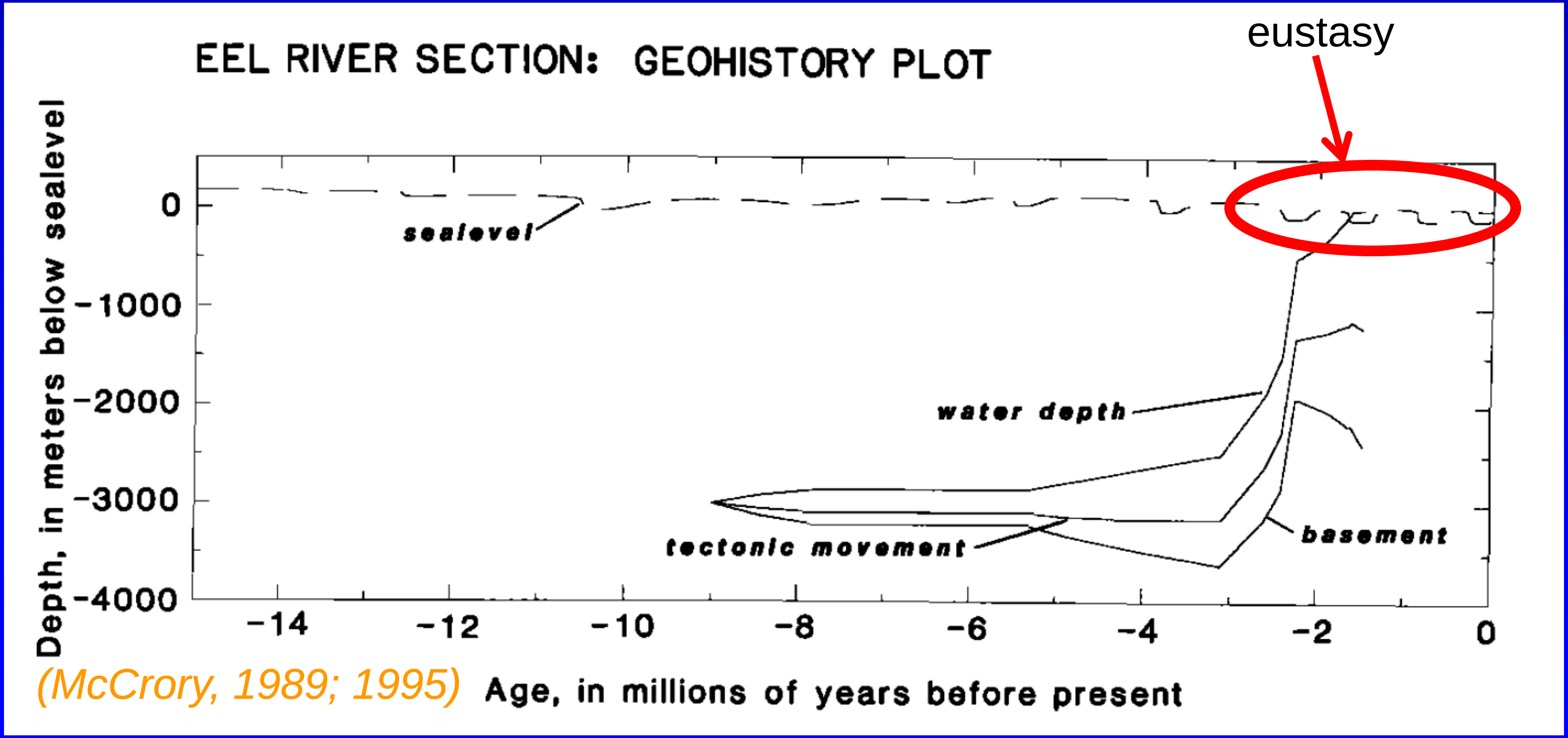


Isopach:
Upper Rio Dell to Top Scotia Bluffs 1 (southern onshore Eel River basin)

Notes by Presenter: Each gross interval isopach map above depicts 10 sq. miles in the vicinity of Grizzly Bluff. Note gross interval thickening to the west and northwest.

2. Onshore Eel River basin

- Eel River basin strata shoaled dramatically in the Pliocene due to isostatic/buoyant effects – subduction of progressively younger, warmer Gorda plate (McCrory, 1989).
- Eustasy has had a comparatively minor role on basin fill (until Recent fluvial deposition).
- Eel River basin strata never subsided enough for hydrocarbon generation to occur



(McCrory, 1989; 1995)

3. Reservoir quality and petroleum system

•Onshore Eel River basin strata contain plenty of sandstone (mostly turbidites and shallow marine).

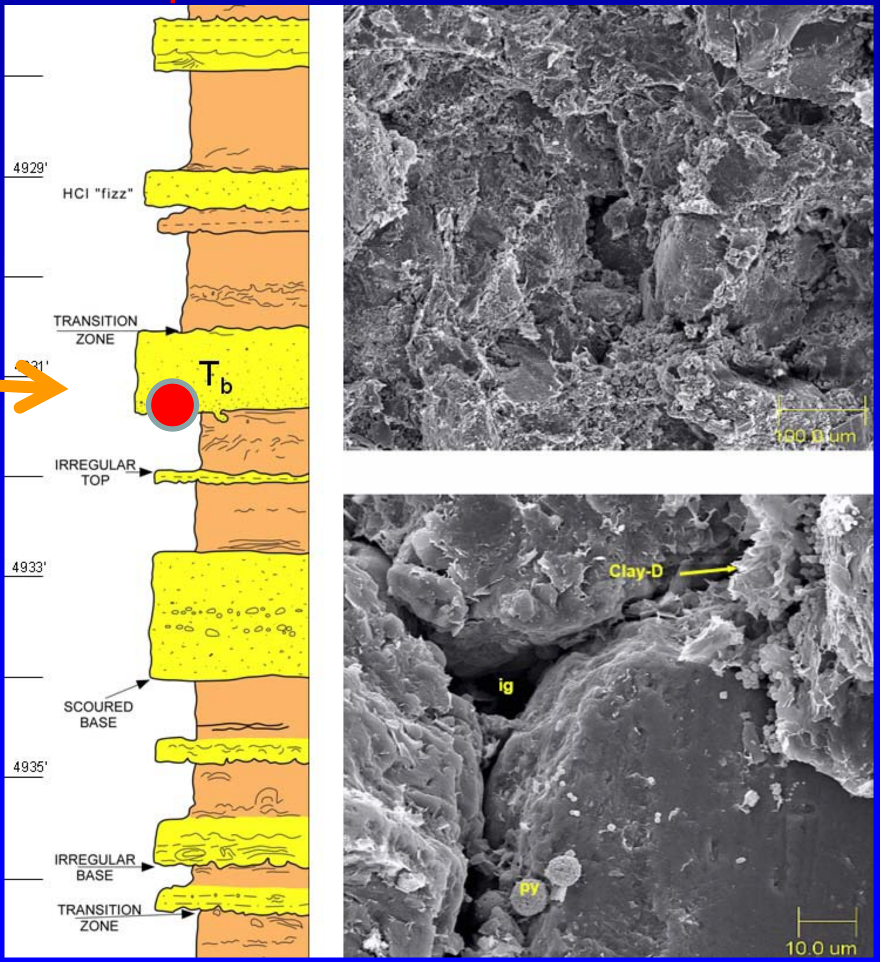
•Economic gas reservoirs of the basin (Anderson sands) have a higher N:G and greater Tmax than the clay-rich lower Rio Dell (thin-bedded turbidites).

•Horizontal perm. values in Anderson submarine fan sands: 20-35 md; por. 17-23%

•Burial history: Eel River basin shales were never buried deeply enough to allow for hydrocarbon generation.

•Source rock for Eel River basin gas is most probably the sheared, deformed Yager complex – part of the accretionary basement (Underwood, 1985).

Example from the lower Rio Dell Fm.



[LRD core with SEM image. Note extensive detrital clays.]

Key points

- Eel River basin exhibits a shoaling-upward stratigraphic trend (in *agreement* with the general models)… However, key tectonically-induced unconformities (late Miocene/basal Pullen and late Pleistocene) – and their stratigraphic signatures – are unique to this basin.

- Pre-dominant role of tectonics as a modulator of stratigraphic infill of accretionary forearc regions

- Accretionary forearc basins usually contain plenty of sand (potential turbidite or shallow marine reservoirs).

- Constraints on hydrocarbon prospectivity in accretionary forearc basins can include insufficient burial depths of source rocks, and loss of seal due to faulting.

- Accretionary wedge shales as source rocks in other accretionary forearc settings?

Thank you.

Questions?