Sedimentation in Continental Rifts and Collisional Orogens: Insights from Southern California and Eastern Taiwan

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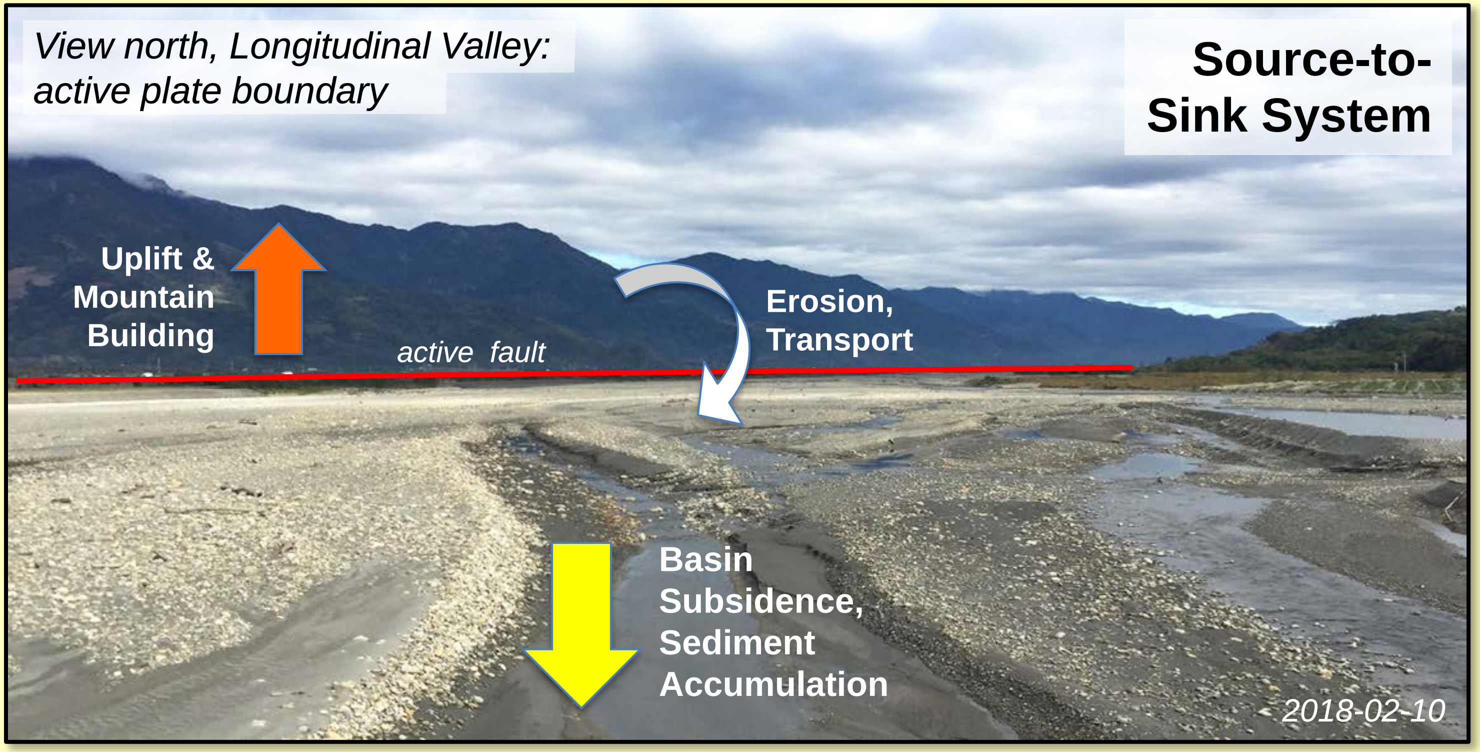
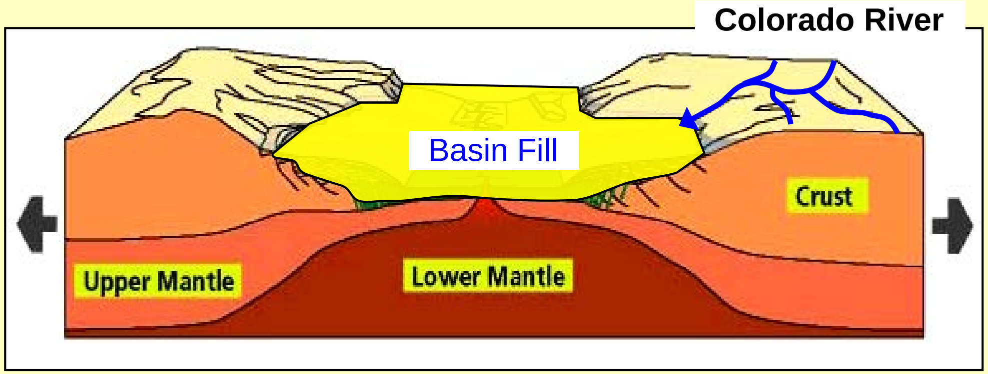


Basin-forming processes in different tectonic settings: One example from each type

(1) CONTINENTAL RIFT

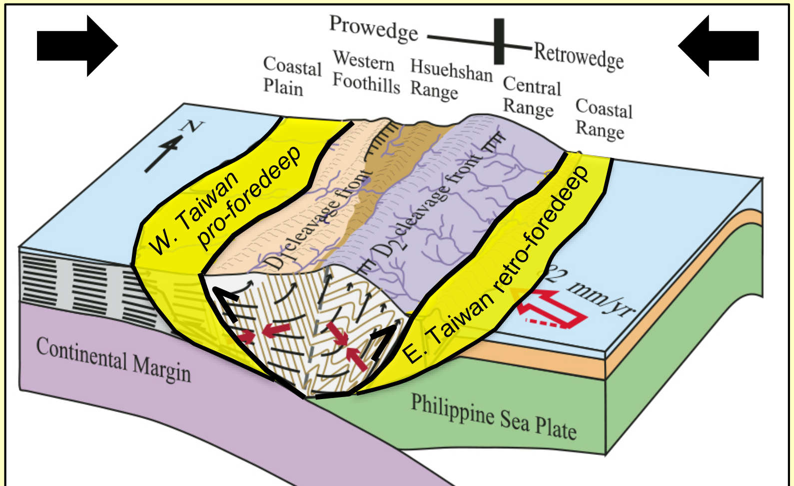
Southern California / NW Mexico



- Oblique-Divergent Plate Boundary
- Extension → Crustal *Thinning*
- Basins Form by Isostatic Subsidence
- Basins Fill with sediment from a single, ***slowly eroding*** large river source (Colorado River) in the past ~5 Myr.

(2) COLLISIONAL OROGEN

Taiwan: East Eurasian Margin

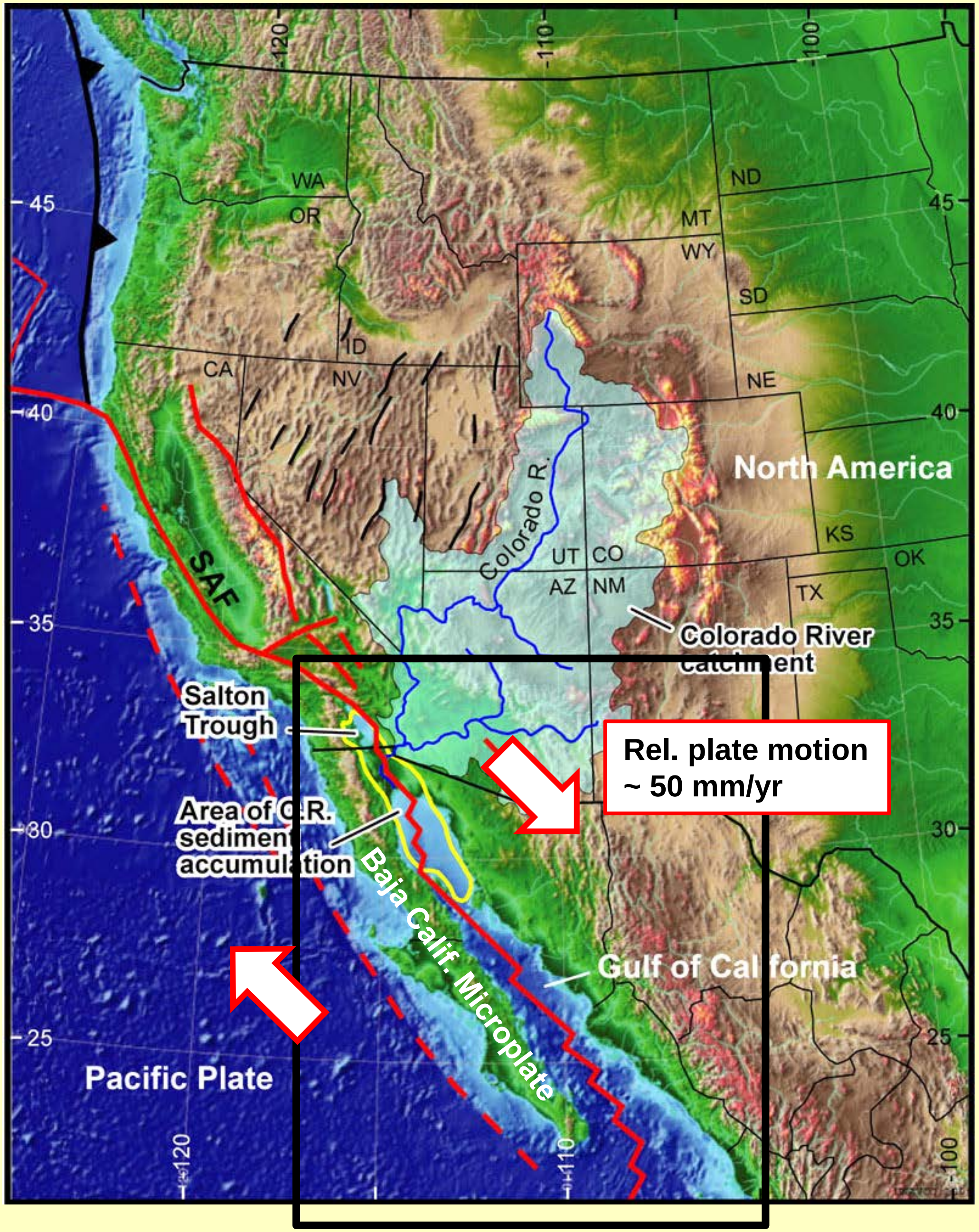


Fisher et al. (2007)

- Oblique-Convergent Arc-Continent Collision
- Shortening → Crustal *Thickening*
- Flexural Subsidence in western pro-foredeep, … *and* in eastern retro-foredeep basin
- Basins Fill with sediment from multiple ***very rapidly eroding*** small rivers (~5 Myr).

Sedimentary Basins: Record of deformation, erosion, subsidence processes.

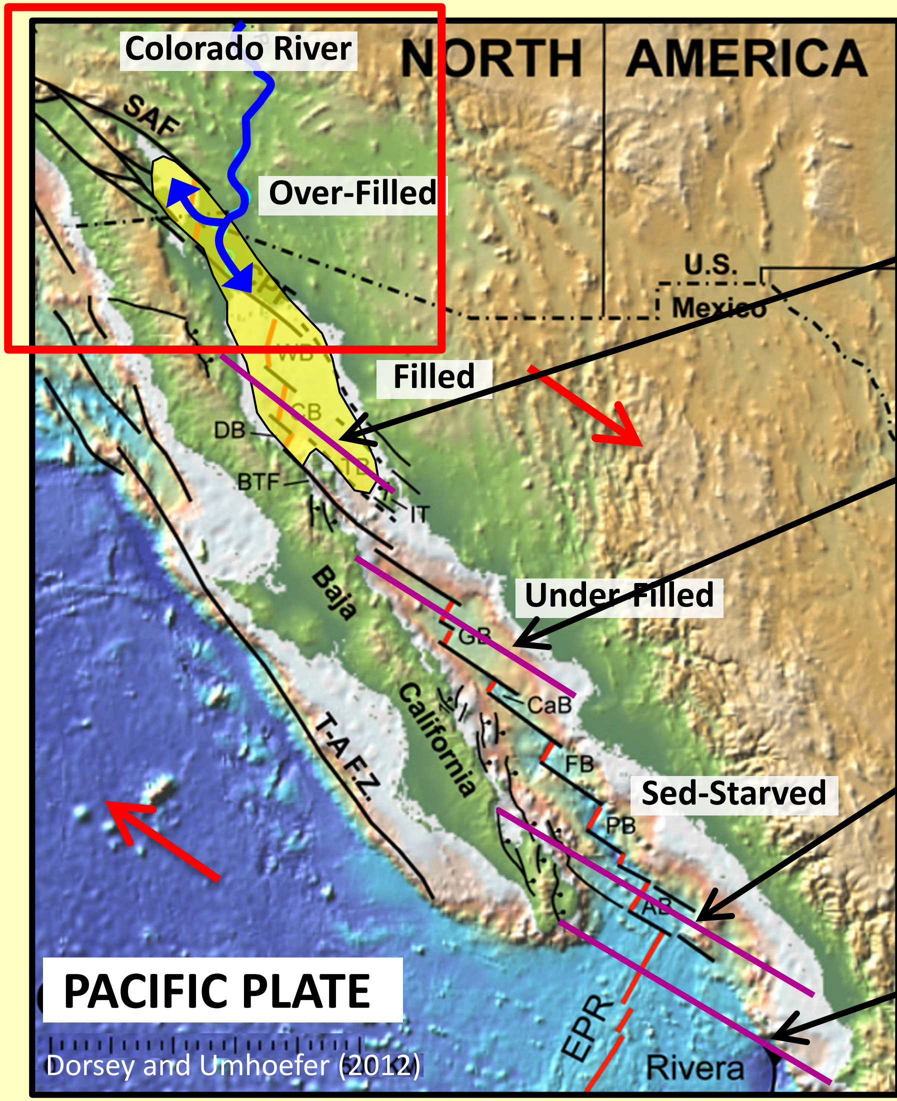
(1) CONTINENTAL RIFT BASINS … Western Margin of North America

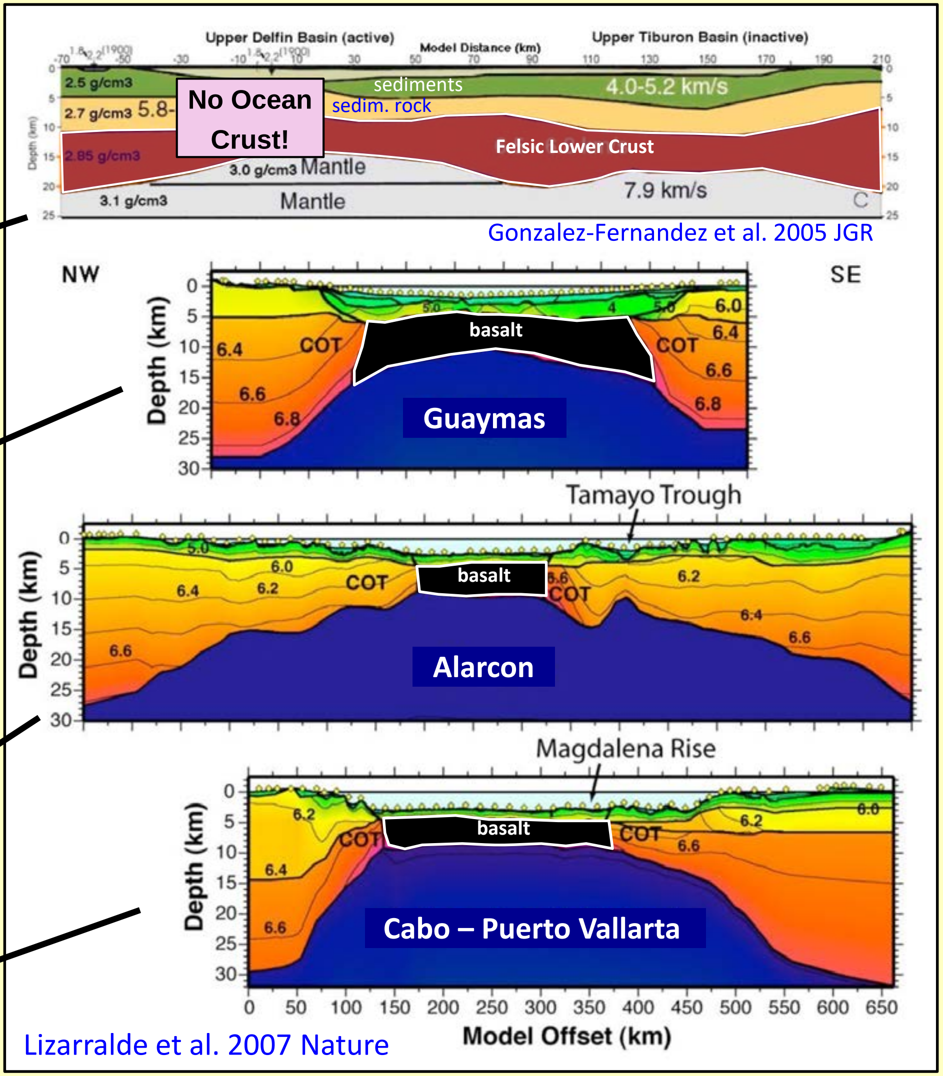


- Pacific-North America plate boundary: ~ 50 mm/yr
- San Andreas Fault in north, Gulf of California in south
- Weak extension in Gulf of California started ~12 Ma.
- Strain localized along plate boundary ~7-8 Ma.
- Baja microplate moves with Pacific plate, rifting away from North America.
- Colorado River: large continent-interior catchment, huge sed flux to basins …

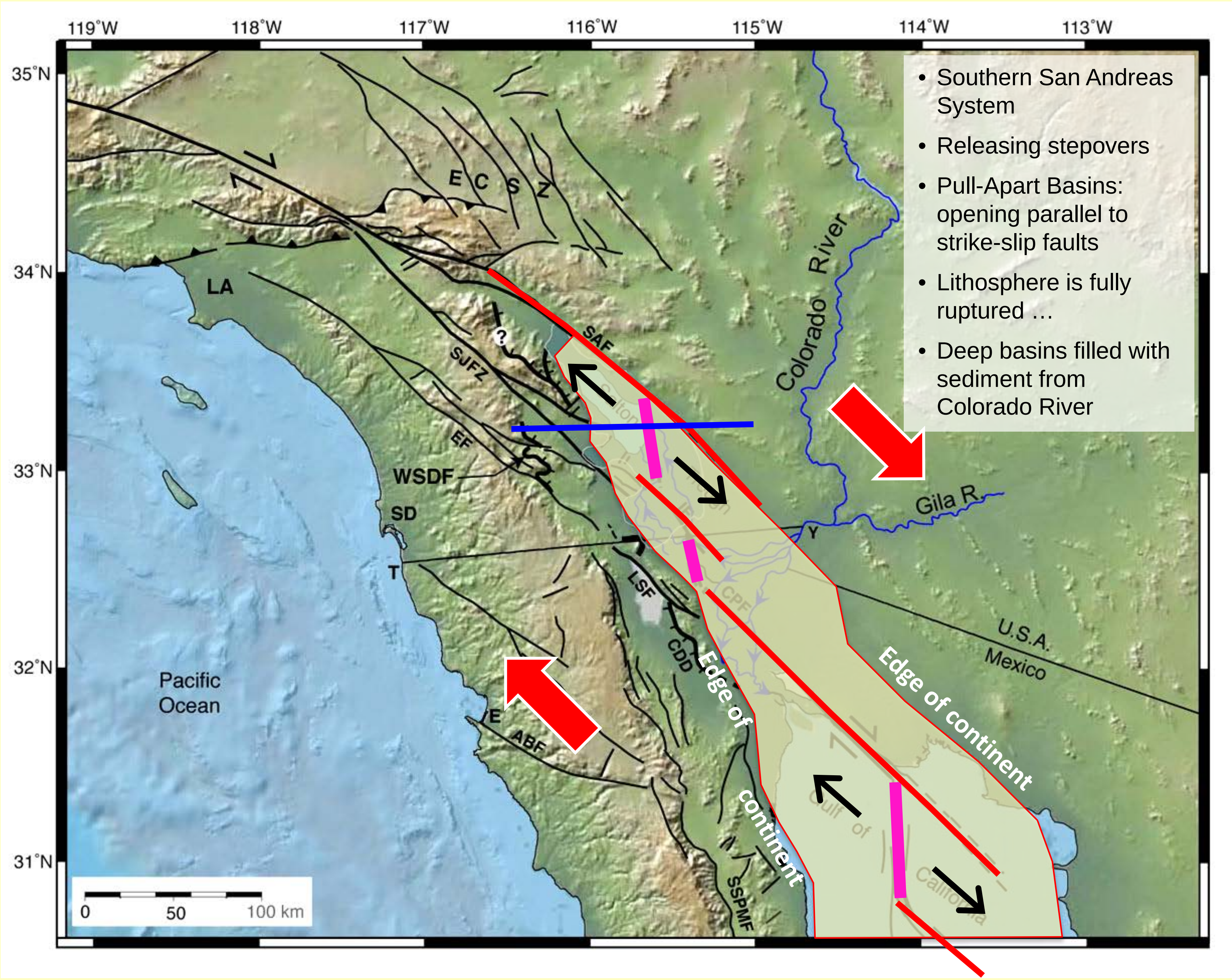
Gulf of California and Salton Trough

- Amount and timing of oblique rifting same along strike: ~350-400 km since ca. 12 Ma.
- **Assess Role of Sediments**: input at point source in north (Colorado River)





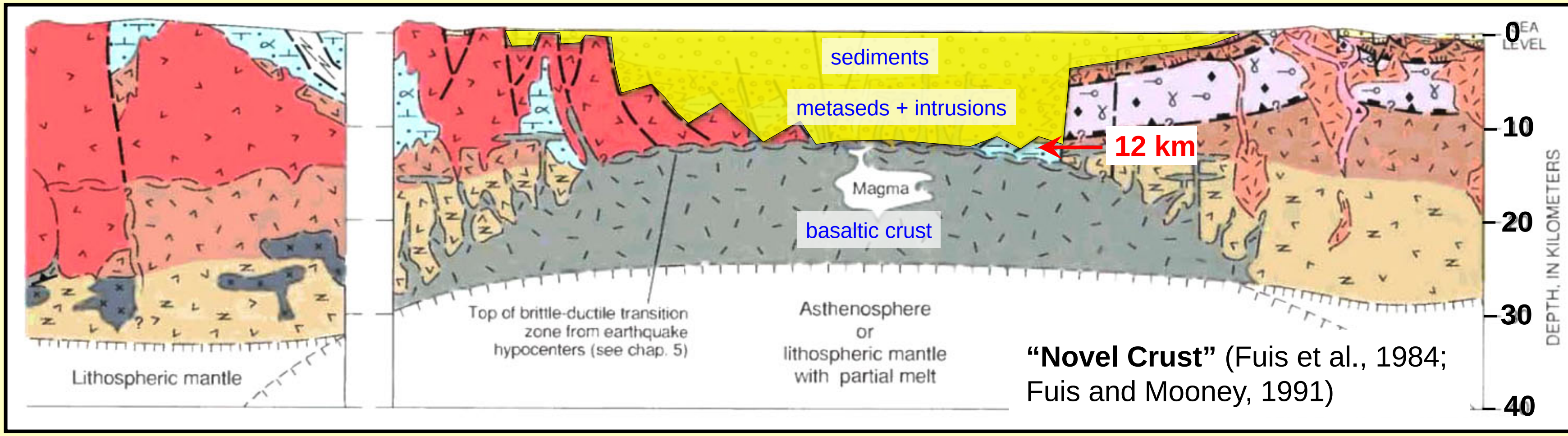
Salton Trough and Northern Gulf of California



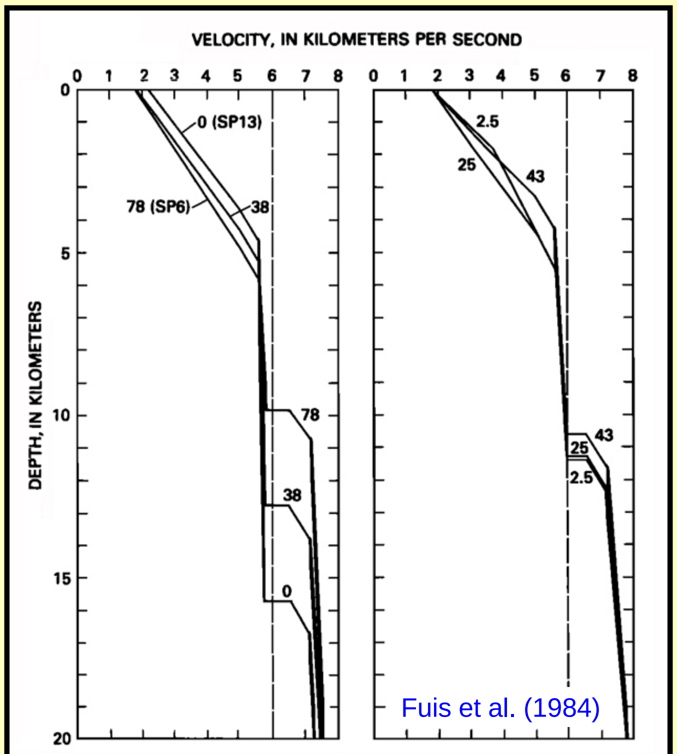
- Southern San Andreas System
- Releasing stepovers
- Pull-Apart Basins: opening parallel to strike-slip faults
- Lithosphere is fully ruptured …
- Deep basins filled with sediment from Colorado River

Crustal Model for Salton Trough (Fuis et al., 1984) – Seismic Refraction:

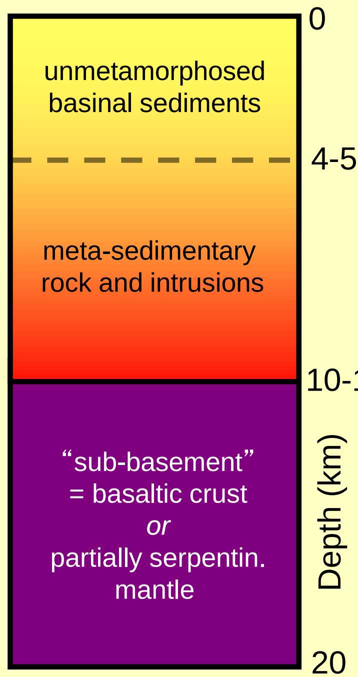
Lithosphere is ***fully ruptured***. Young (post-5.3 Ma) Colorado River sediment and metaseds to depths of 10-12 km



"Novel Crust" (Fuis et al., 1984; Fuis and Mooney, 1991)



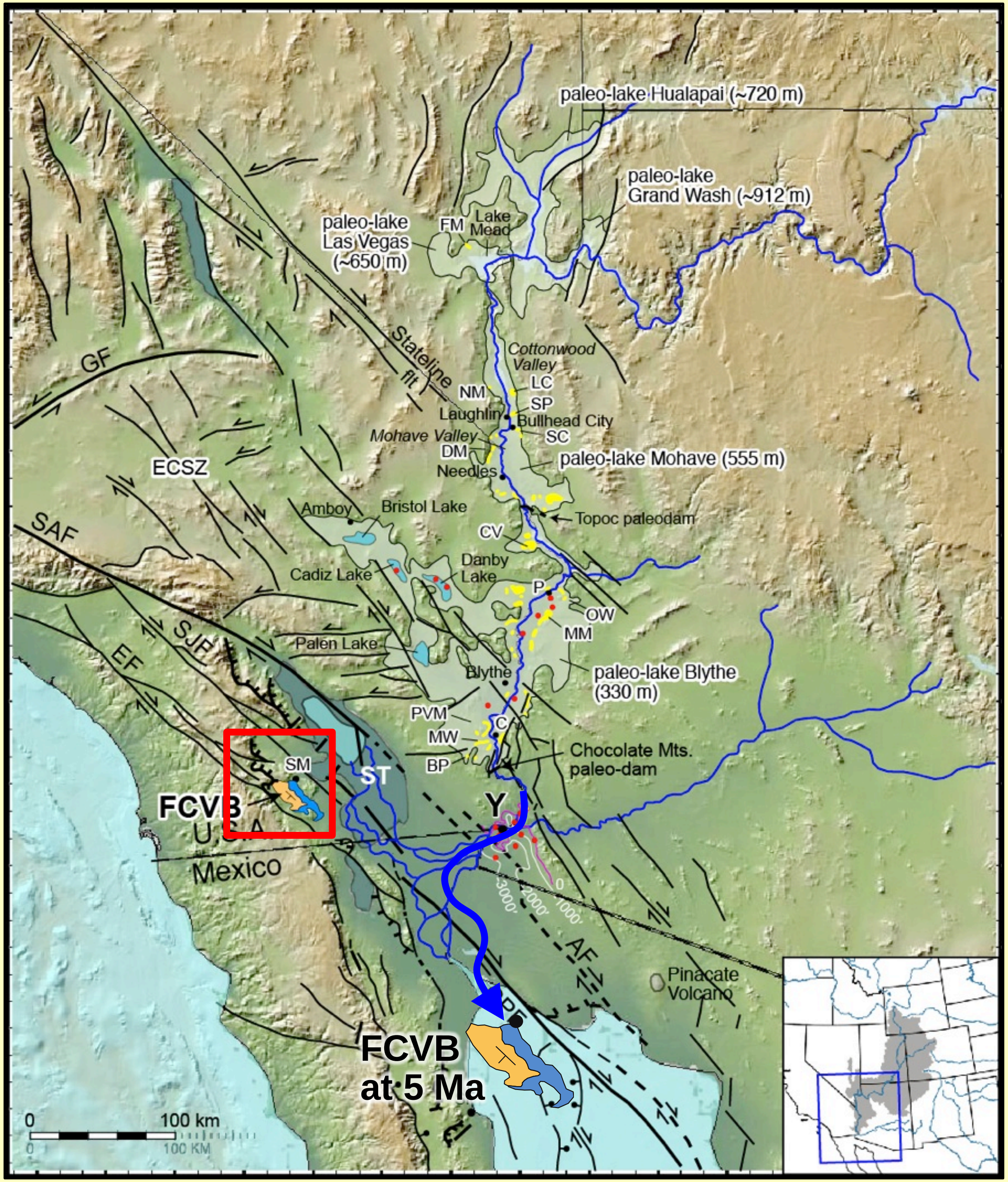
… explains seismic refraction data, velocity structure



(abrupt increase in Vp)

10-12 km in ca. 5 m.y. requires sed accum. rate ~2-3 mm/yr, consistent with measured rates *(Van Andel, 1964; Herzig et al., 1988; Schmitt and Hulen, 2008; Dorsey et al., 2011).*

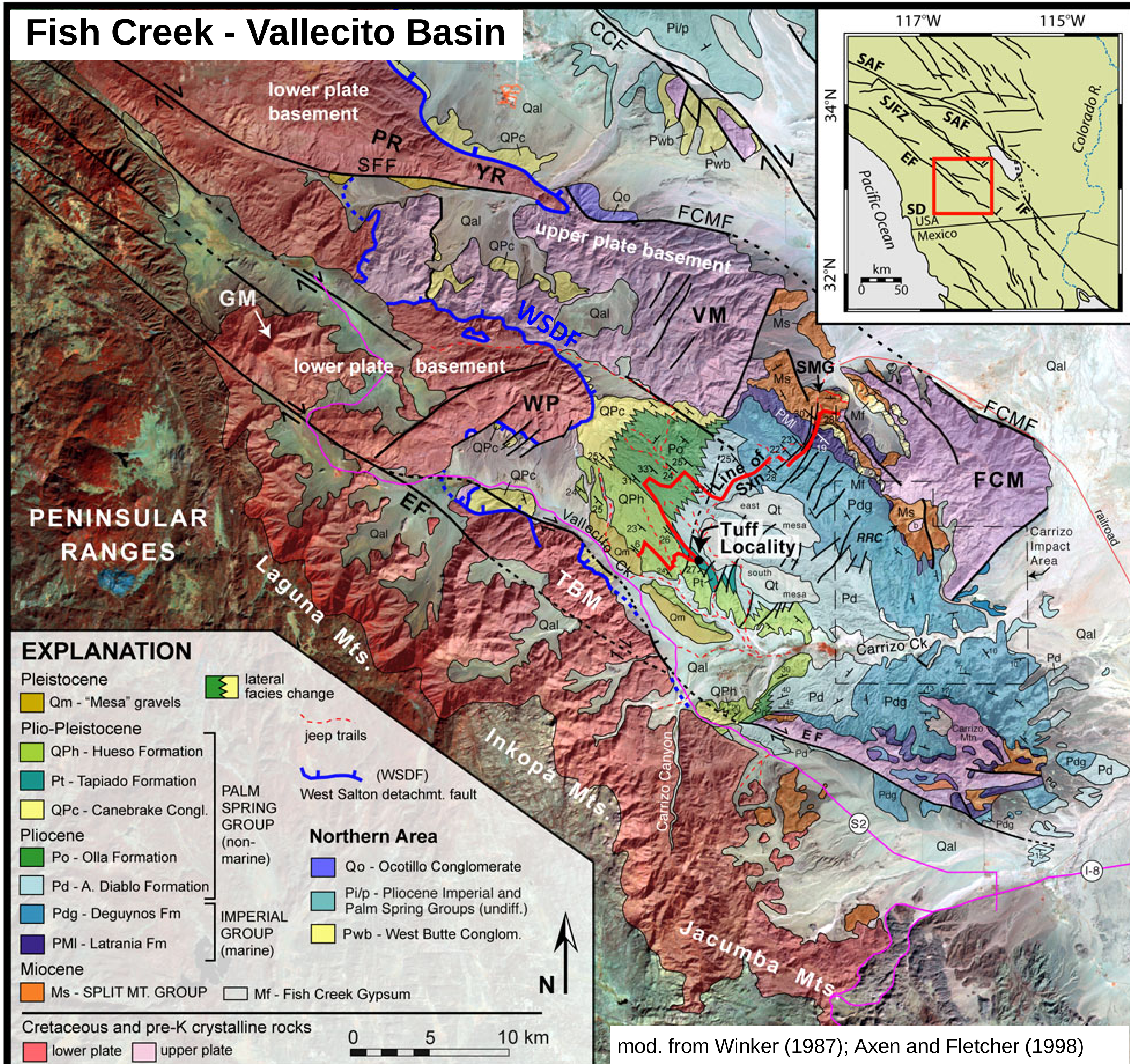
Faster velocities (7.5-8.0 km/s) could be basaltic crust (Fuis et al., 1984) or partially serp. mantle (Nicolas, 1985).



Colorado River:

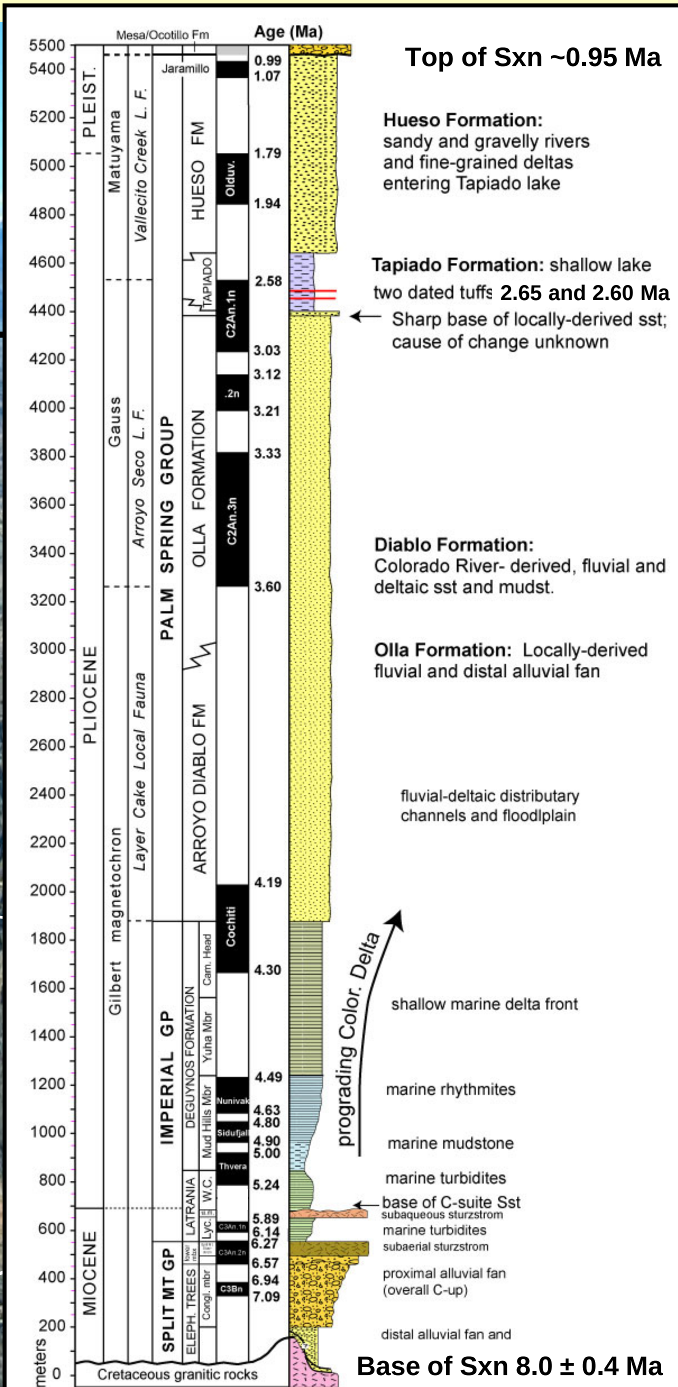
- Flows through complex transtensional domain: *Eastern Calif. Shear Zone*
- **Large Sediment Flux** to plate-boundary sed basins
- **Fish Creek – Vallecito Basin** (FCVB): Late Cz deposits. Filled with thick Col. River sediment starting ~5.3 Ma.
- **Well Exposed** due to recent uplift on young strike-slip faults (initiated ~1.2 Ma) …
- **FCVB Restores to** position south of the mouth of Colorado River at ca. 5 Ma.

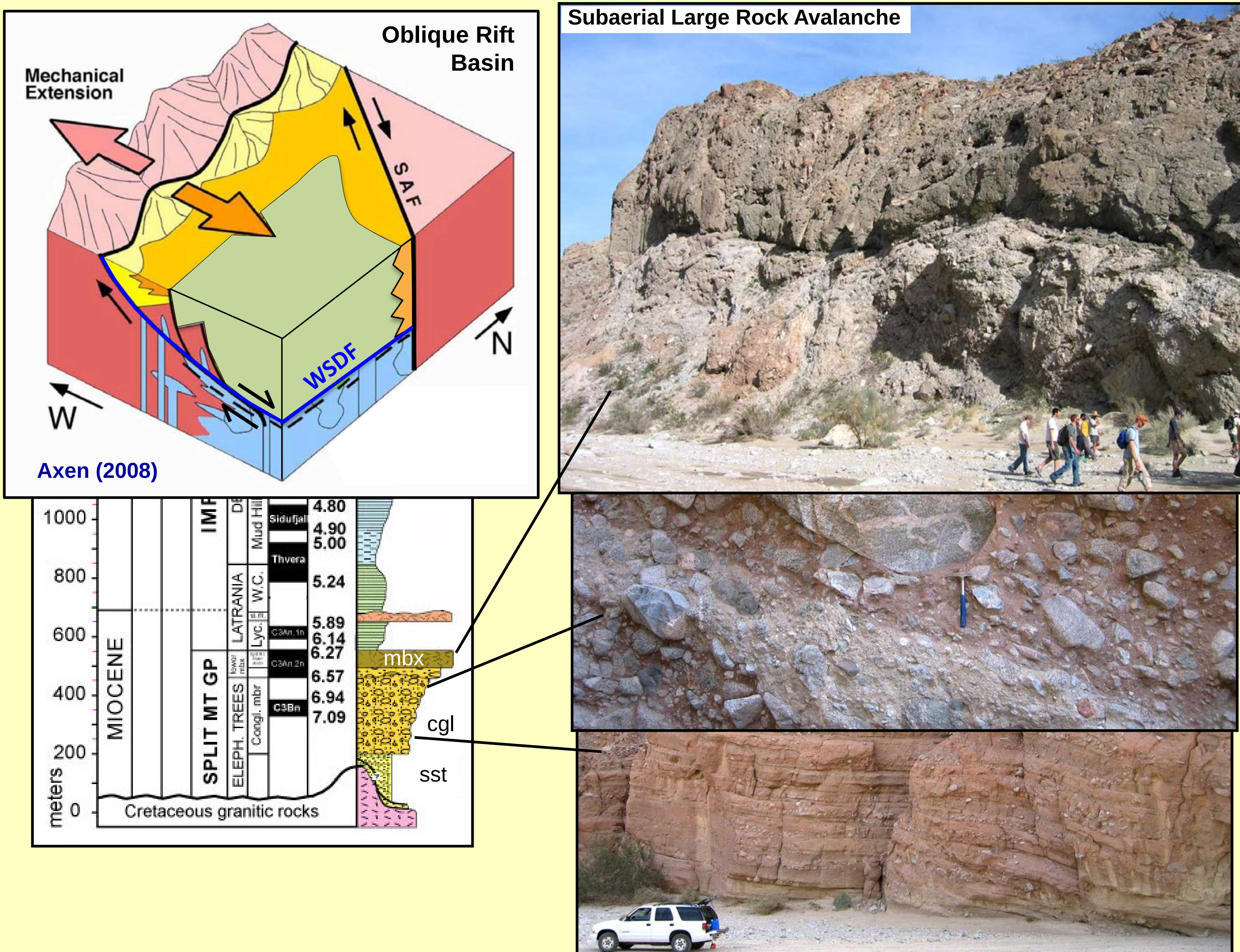
Fish Creek - Vallecito Basin



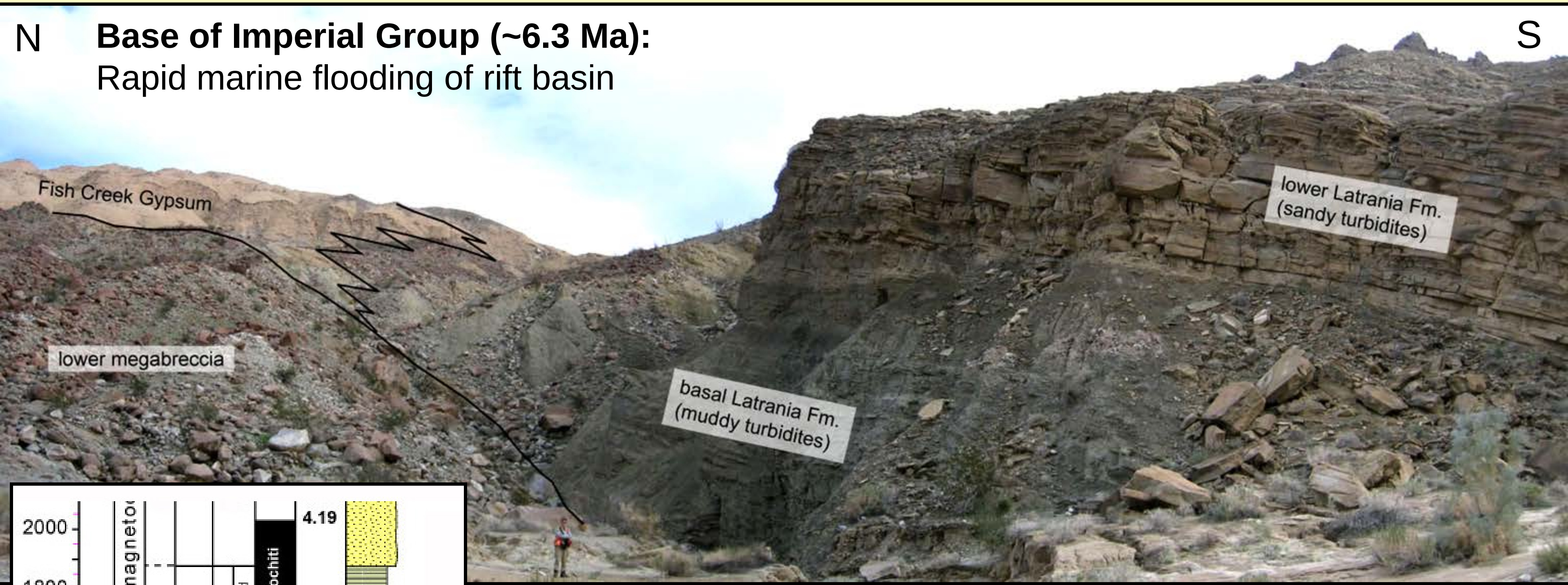
mod. from Winker (1987); Axen and Fletcher (1998)

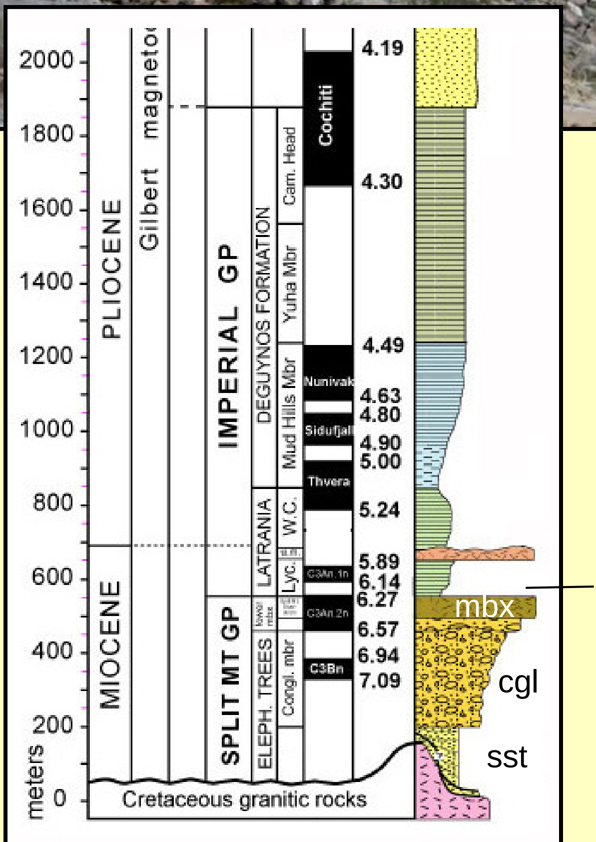
SE **Collab-orators** Gary Axen (N.M. Tech), Susanne Janecke (Utah State Univ.), Bernie Housen (WWU), Kris McDougall (USGS)

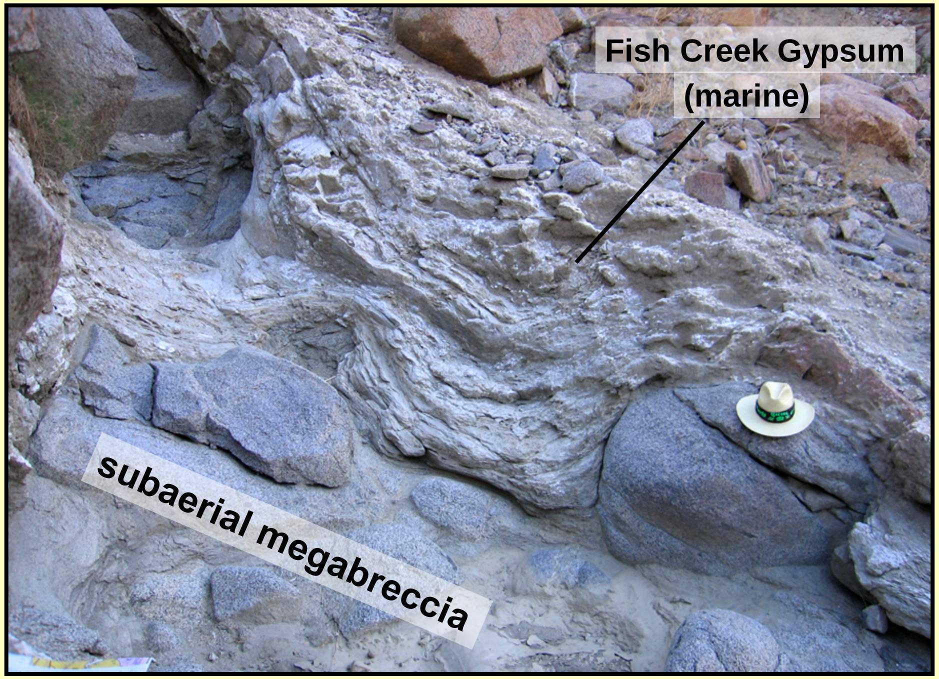



Oblique Rift Basin
Mechanical Extension
SAF
WSDF
W
N
Axen (2008)
1000
800
600
400
200
0
meters
MIOCENE
IMP
SPLIT MT GP
LATRANIA
ELEPH. TREES
lower mbx
Mud Hill
W.C.
Lyc.
Congl. mbr
Sidufjall
Thvera
C3An.1n
C3An.2n
C3Bn
4.80
4.90
5.00
5.24
5.89
6.14
6.27
6.57
6.94
7.09
Cretaceous granitic rocks
mbx
cgl
sst
Subaerial Large Rock Avalanche

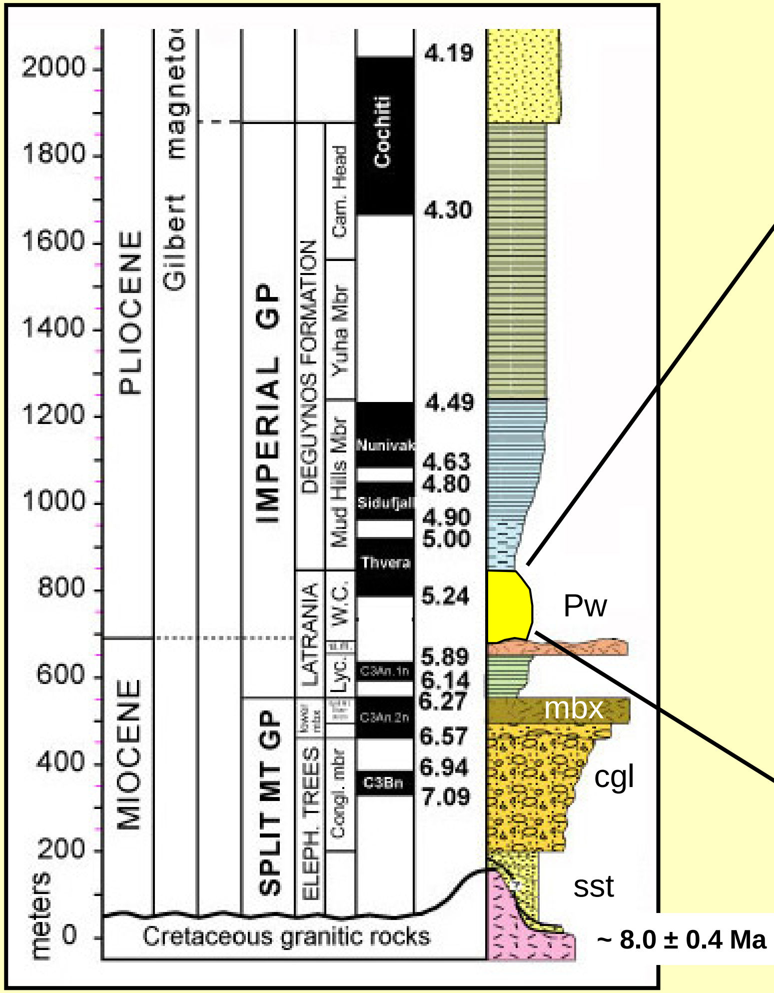
Base of Imperial Group (~6.3 Ma):
Rapid marine flooding of rift basin

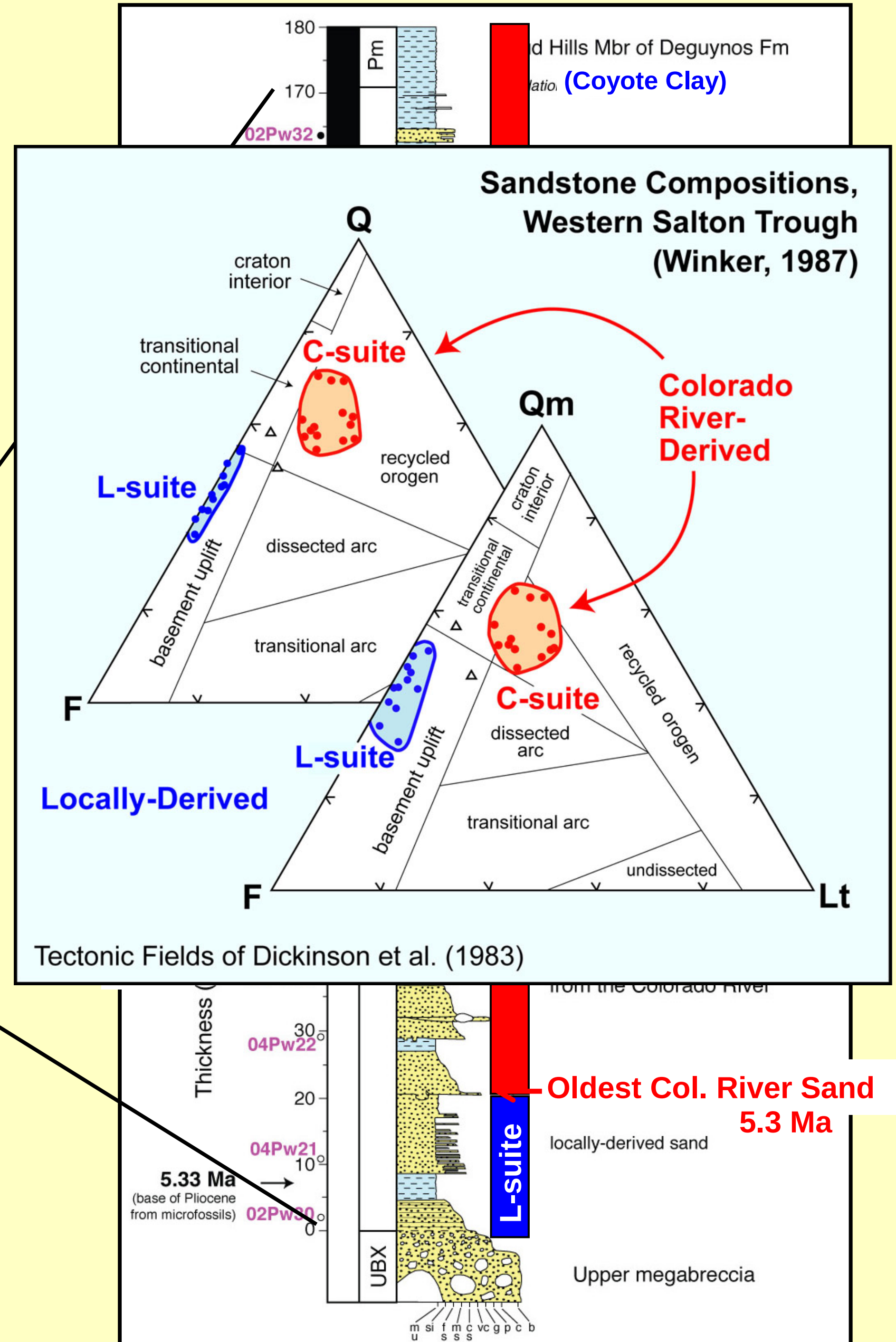


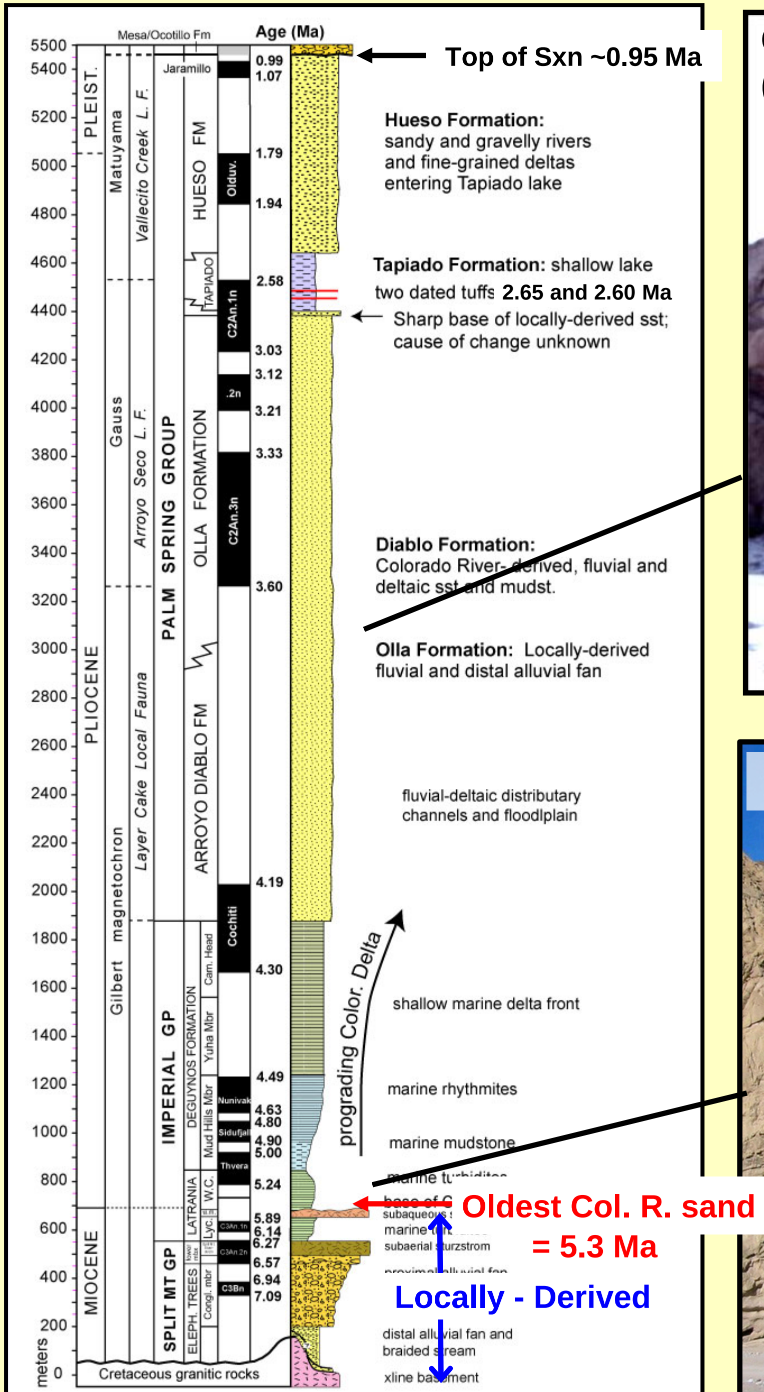




First arrival of Colorado River sand (in marine turbidites)







Age (Ma)
Mesa/Ocotillo Fm
Top of Sxn ~0.95 Ma
Hueso Formation: sandy and gravelly rivers and fine-grained deltas entering Tapiado lake
Tapiado Formation: shallow lake
two dated tuffs 2.65 and 2.60 Ma
Sharp base of locally-derived sst; cause of change unknown
Diablo Formation: Colorado River-derived, fluvial and deltaic sst and mudst.
Olla Formation: Locally-derived fluvial and distal alluvial fan
fluvial-deltaic distributary channels and floodplain
shallow marine delta front
prograding Color. Delta
marine rhythmites
marine mudstone
Oldest Col. R. sand
= 5.3 Ma
subaerial sturzstrom
Locally - Derived
distal alluvial fan and braided stream
xline basement
Cretaceous granitic rocks
meters
PLEIST.
PLIOCENE
MIOCENE
Matuyama
Gauss
Gilbert magnetochron
Vallecito Creek L. F.
Arroyo Seco L. F.
Layer Cake Local Fauna
PALM SPRING GROUP
IMPERIAL GP
SPLIT MT GP
HUESO FM
TAPIADO
OLLA FORMATION
ARROYO DIABLO FM
DEGUYNOS FORMATION
LATRANIA
ELEPH. TREES
Jaramillo
Olduv.
C2An.1n
C2An.3n
Cochiti
Nunivak
Sidufjall
Thvera

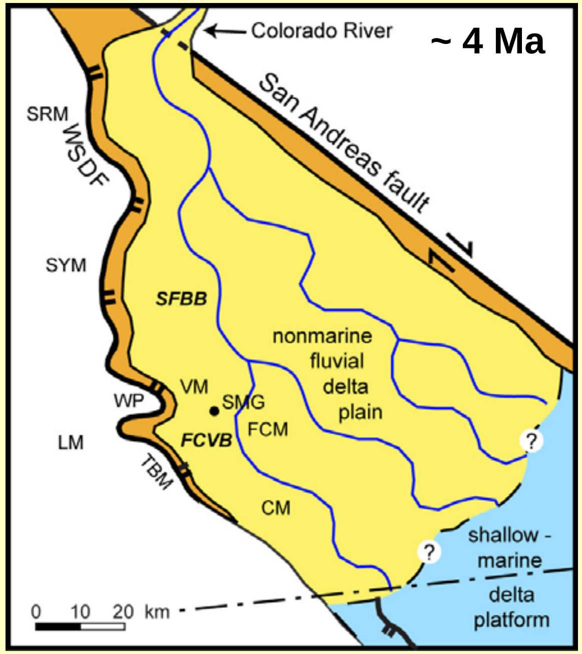
Colorado River sediments (A. Diablo Fm)

marine turbidites (Wind Caves Mbr)

Sediment Budget / Mass Balance

(Dorsey & Lazear, 2015; Dorsey et al., 2018)

- Total C.R. Sed Volume in Basins: $2.8 \pm 0.6 \times 10^5$ km^3, since 5.3 Ma
- Early Pliocene (5.3–5.0 Ma) river sediment discharge: ~ 5-10 Mt/yr
- Short-lived hiatus (Coyote Clay)
- Post-4.8 Ma sediment discharge: 172 ± 66 Mt/yr (= modern C.R. flux)
- Suggests *major increase* in river sediment output at ~ 4.8 Ma.

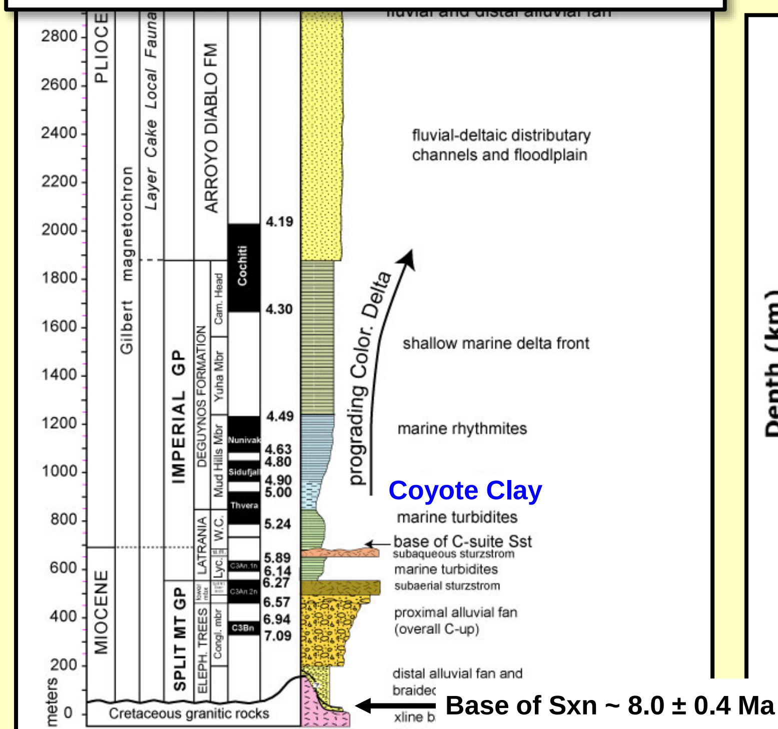


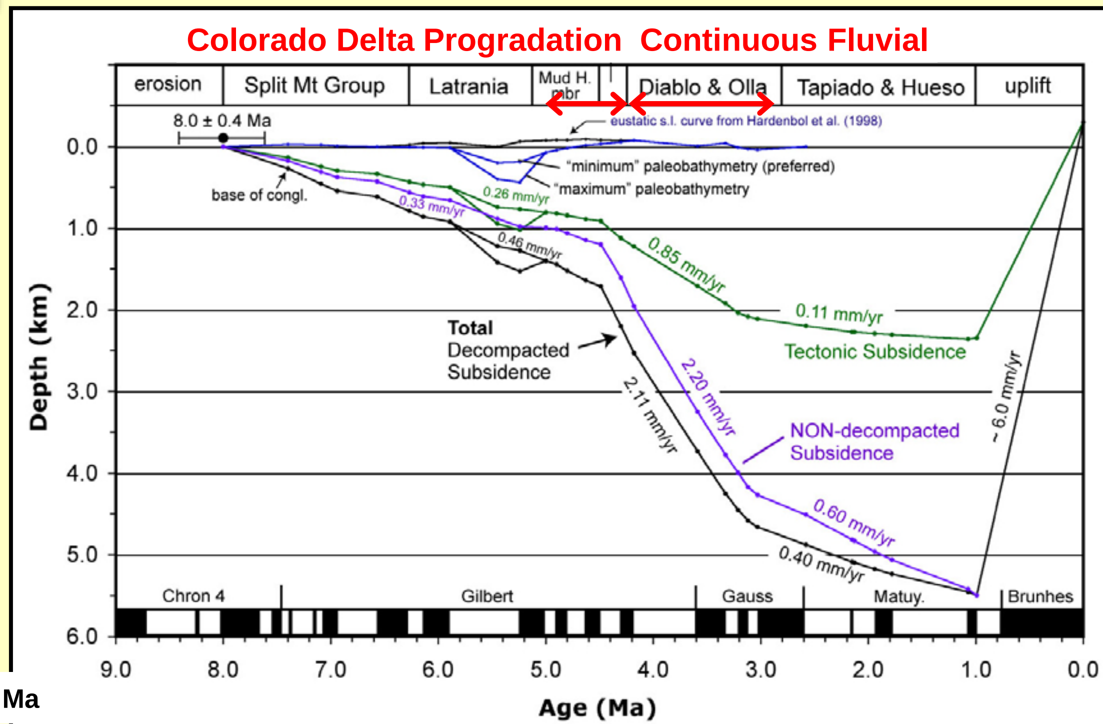
Delta Prograded

during abrupt increase in subsidence rate, fluvial conditions persisted during rapid subsidence.

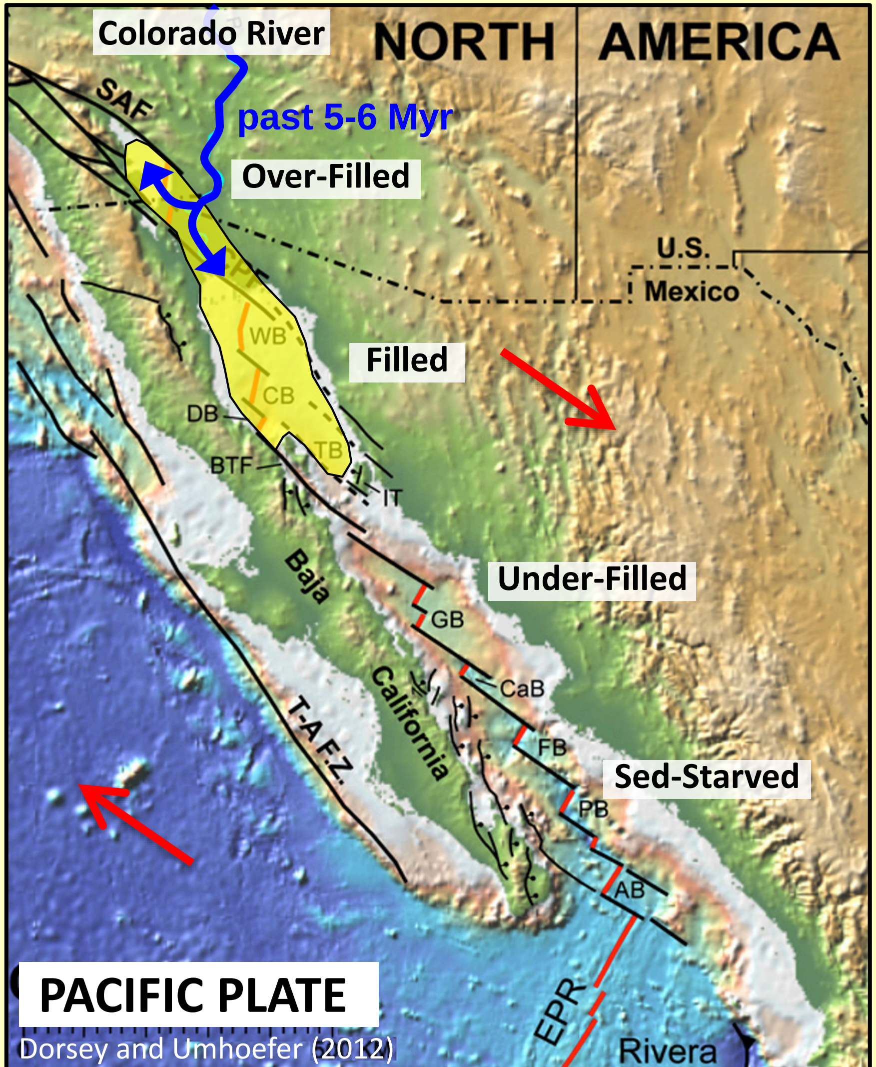
Requires large increase in sediment flux rate. Seen in other supply-driven delta systems

(Goodbred and Kuehl, 2000; Carvajal and Steel, 2006)

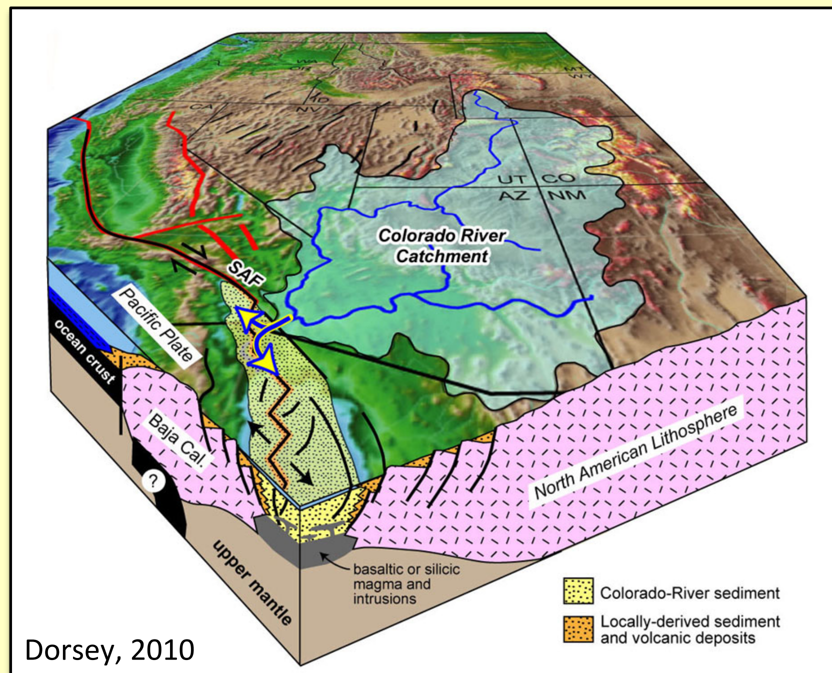




Complex Feedbacks: Extension, Subsidence; *Voluminous Sediment Input;* Paleo-Depositional Environments; Crustal Composition & Architecture ...



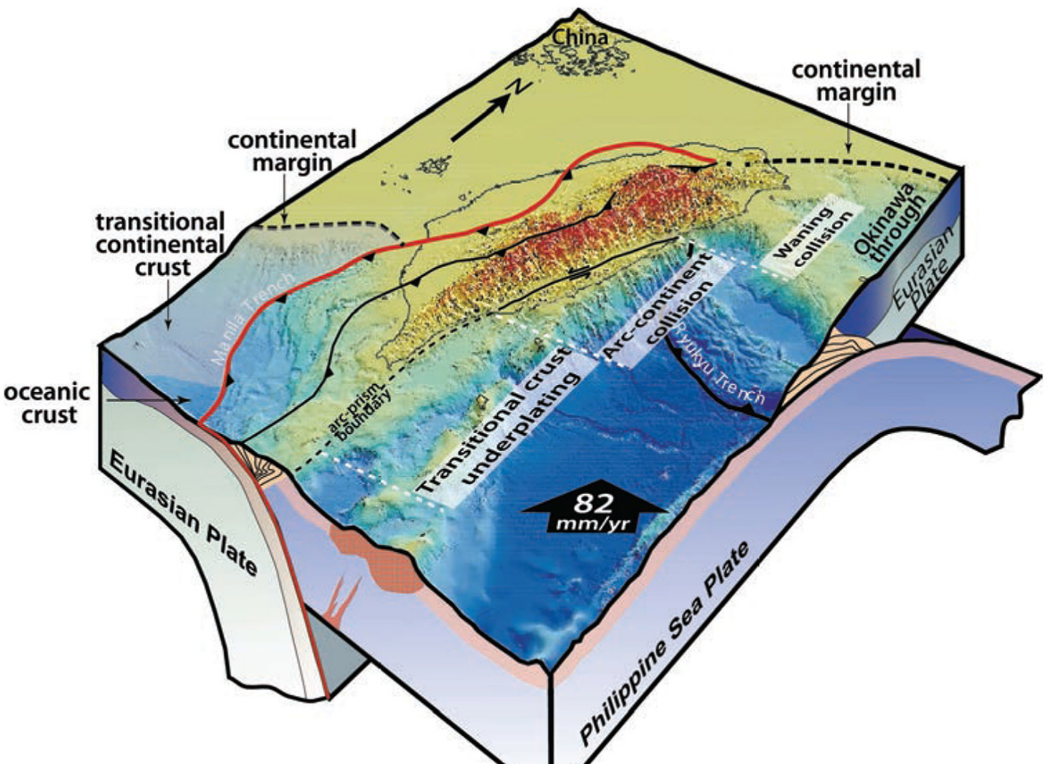
- Inhibits creation of basaltic crust, Prevent formation of new ocean basin
- Creates a new generation of crust: 10-12 km of metasediment with intrusions.
- Important process of crustal recycling, likely active in other rift systems.



(2) COLLISIONAL OROGEN: Taiwan
Test popular tectonic model: Doubly vergent orogenic wedge

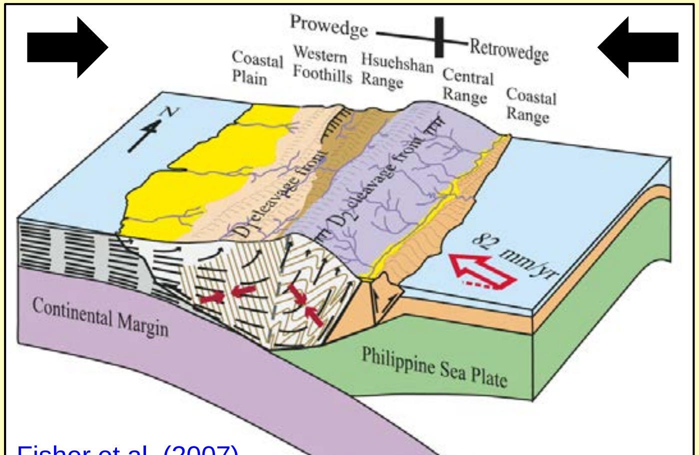
TAIWAN: Modern arc-continent collision

<u>Feedbacks</u>: mountain building, uplift, erosion, sediment routing, basin subsidence & filling

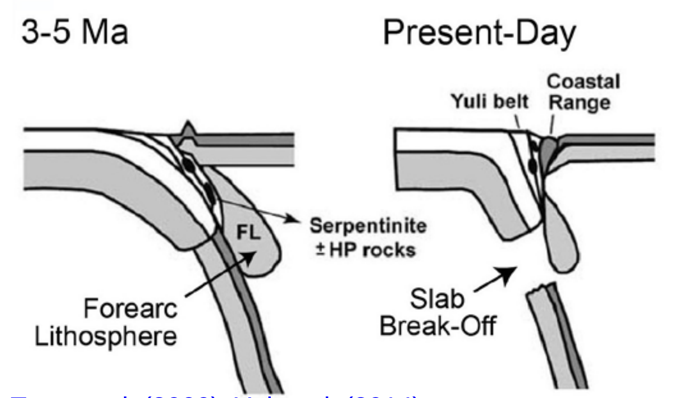


Messales (2014)

Tectonic Models (many)



Fisher et al. (2007)



Teng et al. (2000); Yui et al. (2014)

Doubly-Vergent Orogenic Wedge Model: General

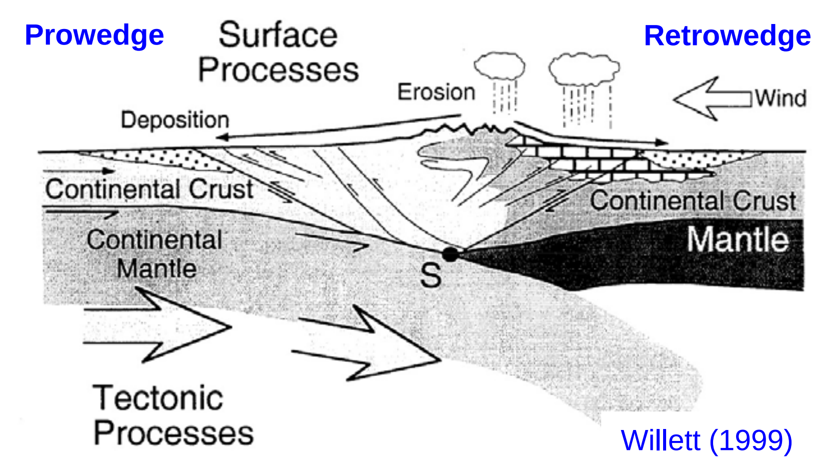


Figure 1. Conceptual view of the feedbacks inherent to the tectonic, surficial, and climatic processes in orogenesis.

- 2D finite-element model: critical wedge undergoing visco-plastic crustal deformation and erosion …
- Flux of material into orogen by accretion (on left) is balanced by erosion of material from the surface.
- Surface Erosion: set of physical rules that simulate fluvial incision and hillslope diffusion.
- Mass flux results in advection of crust … ***through the prowedge into the retrowedge***
- ***Assumes topographic and flux steady-state***

(Willett et al., 1993; Willett, 1999; other papers)

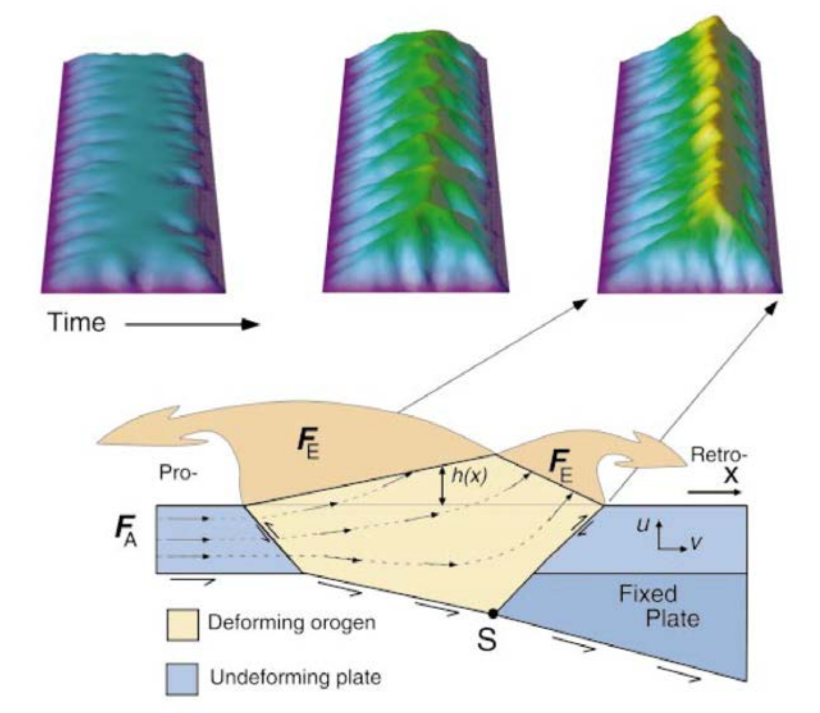


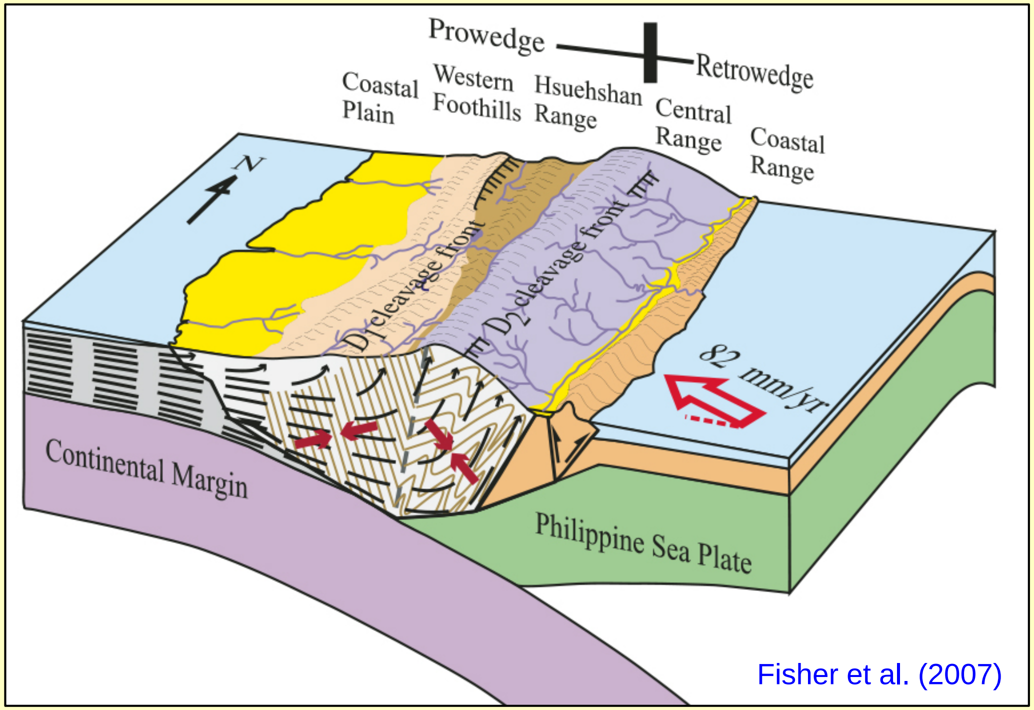
Figure 1. Kinematic model for convergent orogen, driven by plate subduction and accretion. Accretionary flux, F_A, and erosional flux, F_E, determine material transport (dashed lines), with vertical and horizontal components *u* and *v*, respectively. Upper illustrations show topography predicted from surface-process model driven by constant tectonic uplift and constant horizontal shortening rate. Rightmost upper illustration is in topographic steady state as defined by mean cross-sectional form. Willett & Brandon (2002)

ASSUMPTIONS:

(1) Long-term steady state balance.

(2) Little or no transfer of crust from over-riding plate into the orogenic wedge.

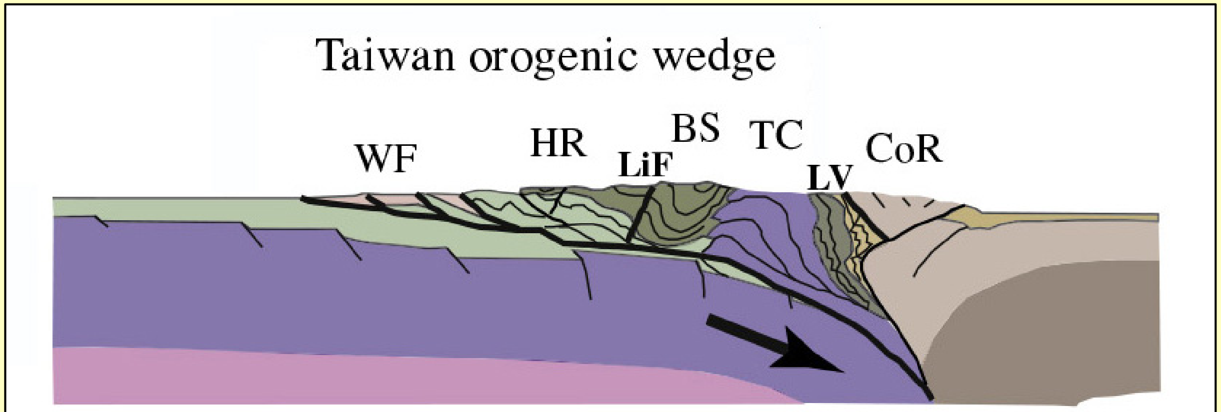
Doubly-Vergent Orogenic Wedge Model: Applied to Taiwan



Fisher et al. (2007)

Taiwan Collisonal Orogen:

- Low-taper <u>prowedge</u> verges toward the subducting plate (Eurasia)
- High-taper <u>retrowedge</u> verges toward over-riding plate (PSP)
- Crest of the range is the boundary between the opposing wedges.
- **No transfer of crust** from Philippine Sea Plate into orogenic wedge
- **Assumes steady-state behavior.**

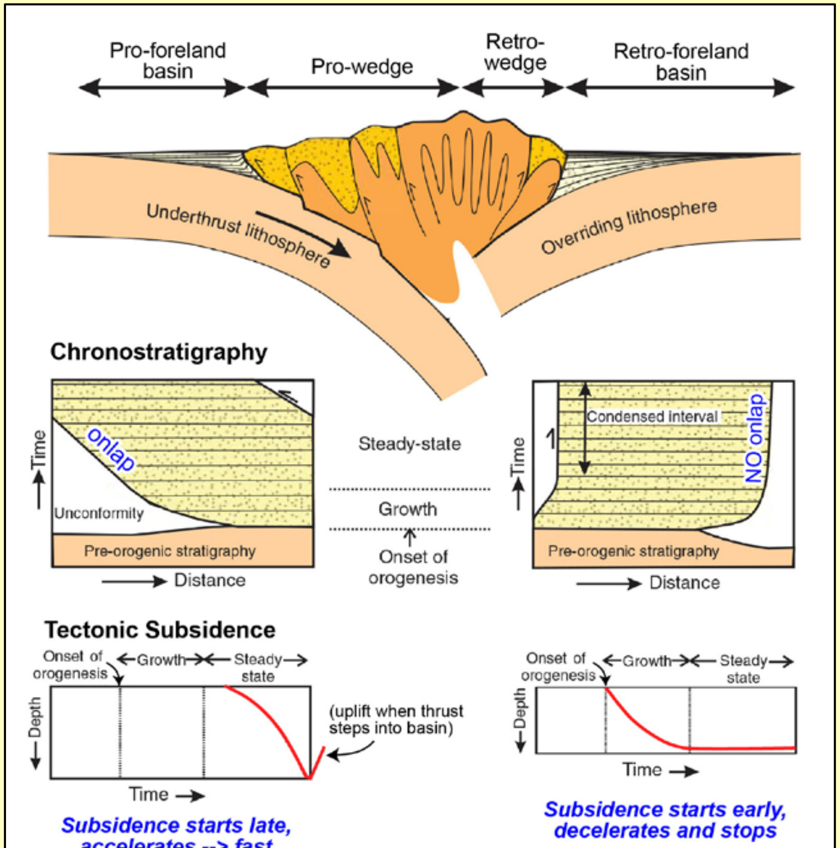


Simoes et al. (2012)

In these models:

- **Tananao Complex (Yuli & Tailuko belts)** = crust of Eurasian margin, under-plated into thrust belt.
- **No transfer of crust** from Philippine Sea Plate into orogenic wedge.

Predictions of the Doubly-Vergent Wedge Model for Sedimentary Basins



Modified from Sinclair (2012)

Pro-foreland basin (FLEXURAL SUBSIDENCE):

- ***Thrust belt migrates toward basin*** …
- Subsidence driven by subduction of plate beneath the orogen: starts slow, accelerates → fast.
- Abrupt change to uplift when basin is incorporated into the converging-migrating thrust belt.

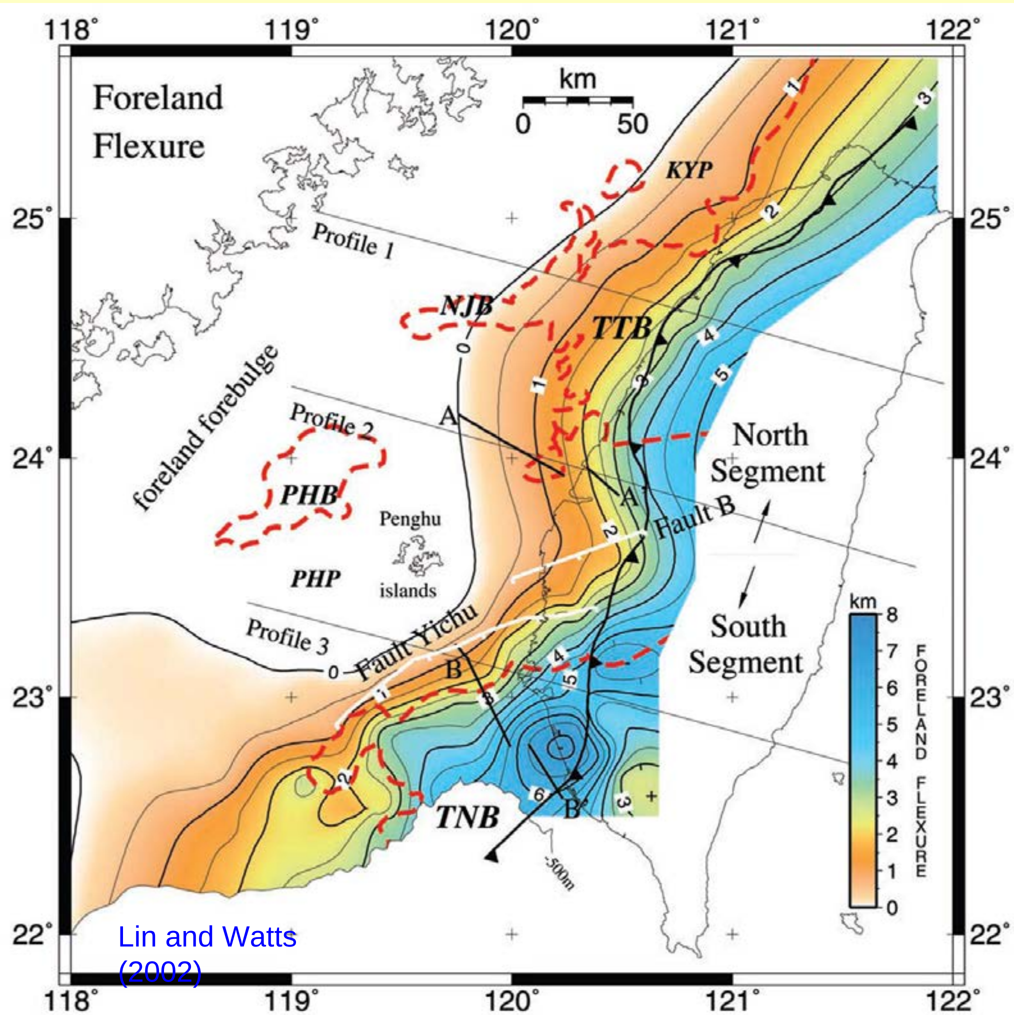
Retro-foreland basin (ALSO FLEXURAL):

- ***Thrust belt does not migrate toward basin*** …
- Subsidence is slow because the only driver is intermittent growth of the retro-wedge.
- No uplift at end, not incorporated into thrust belt.

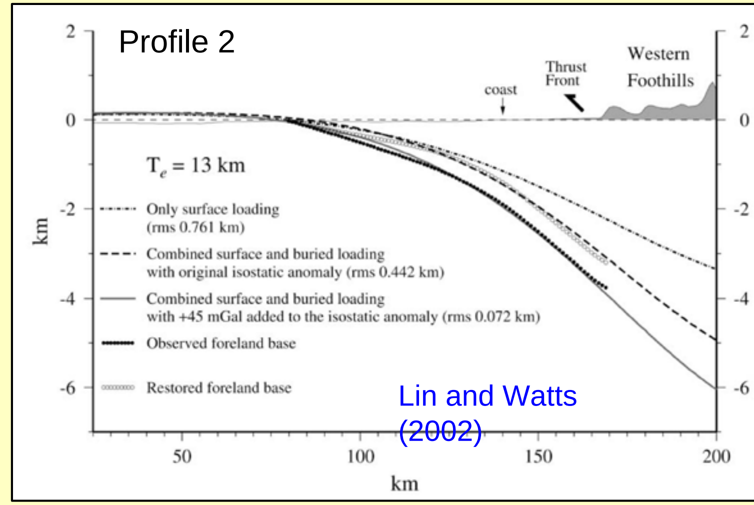
"Type examples include Taiwan, the European Alps, and the Pyrenees." (Sinclair, 2012)

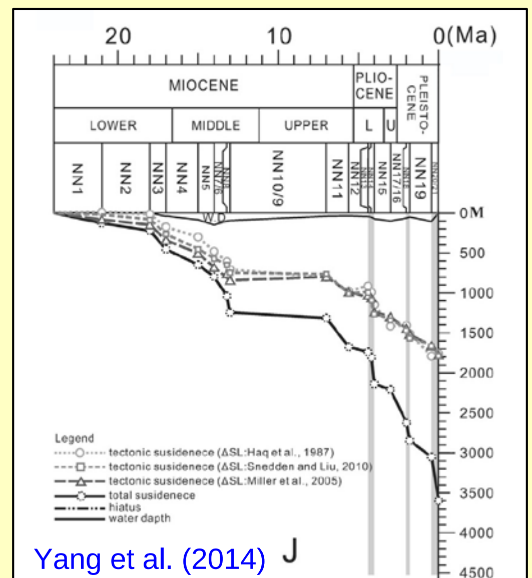
Do Taiwan Basins Fit Predictions of Doubly-Vergent Wedge Model ?

- **In the <u>Western Prowedge Thrust Belt</u> and Foredeep Basin: YES**



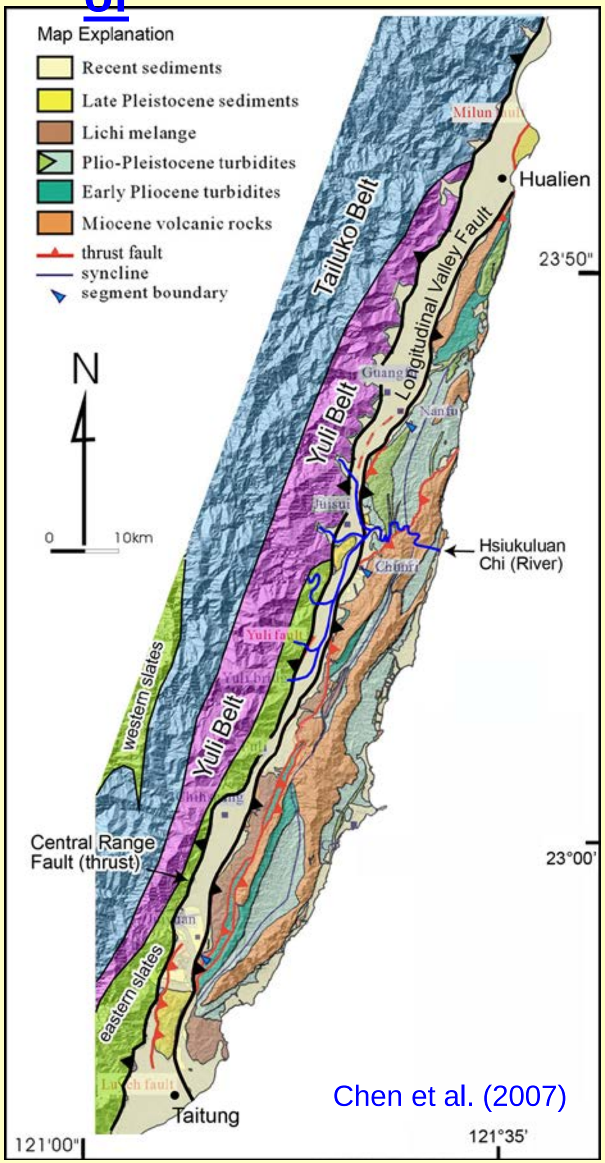
Depth to base of foreland basin sequence, western Taiwan

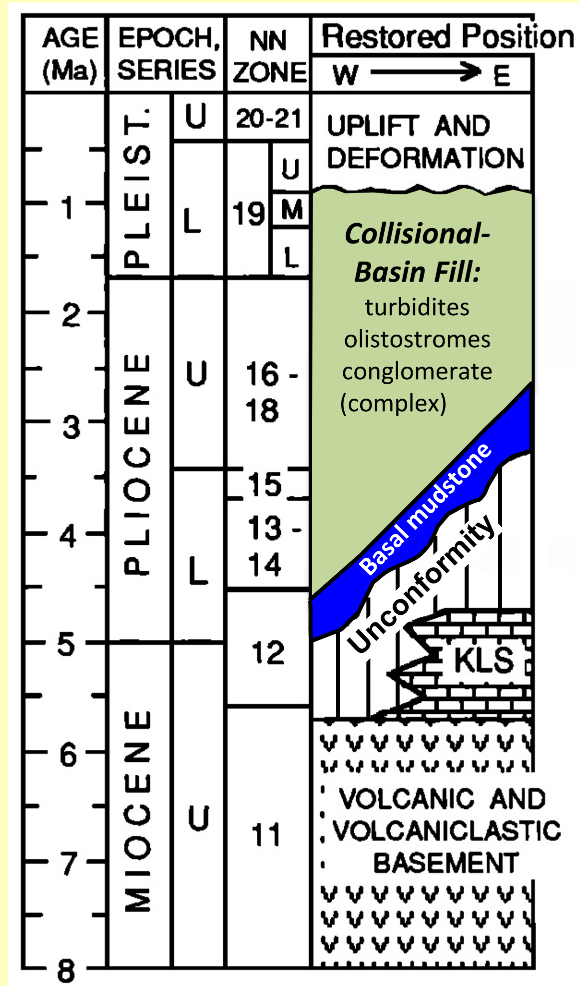


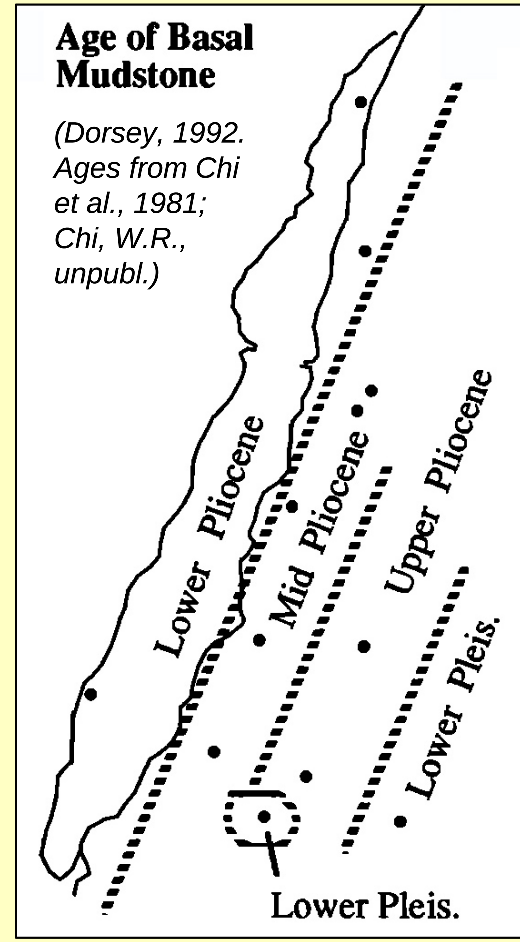


Do Taiwan Basins Fit Predictions of Doubly-Vergent Wedge Model ?

- In Eastern Retrowedge and Syn-Collision Basin (Coastal Range): Sort of

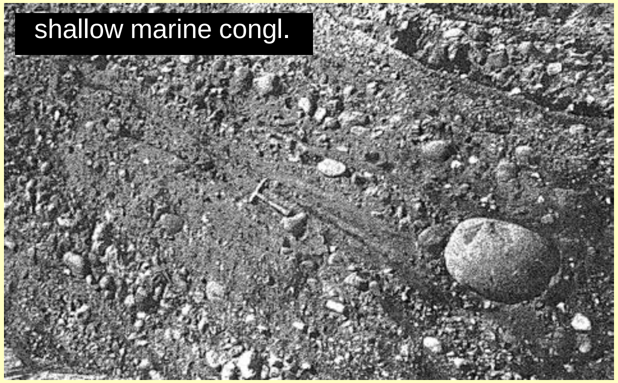


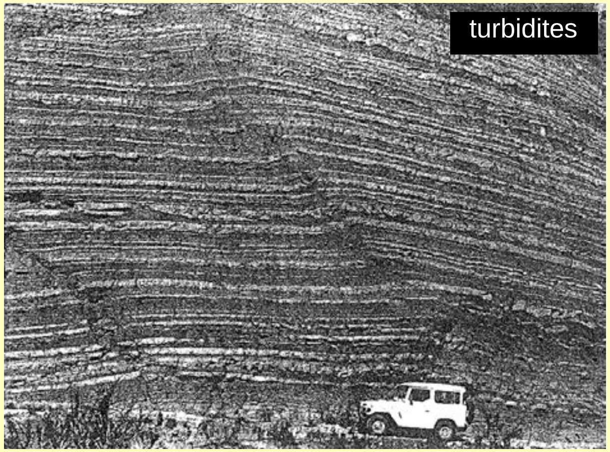




- Regional Unconformity: Separates older Tuluanshan Fm and Kangkou Limestone from thick syn-orogenic marine deposits.
- Mudstone above unconformity youngs to east (restored coordinates)

Eastern Taiwan Coastal Range: Syn-Collision Basin Fill Sequence



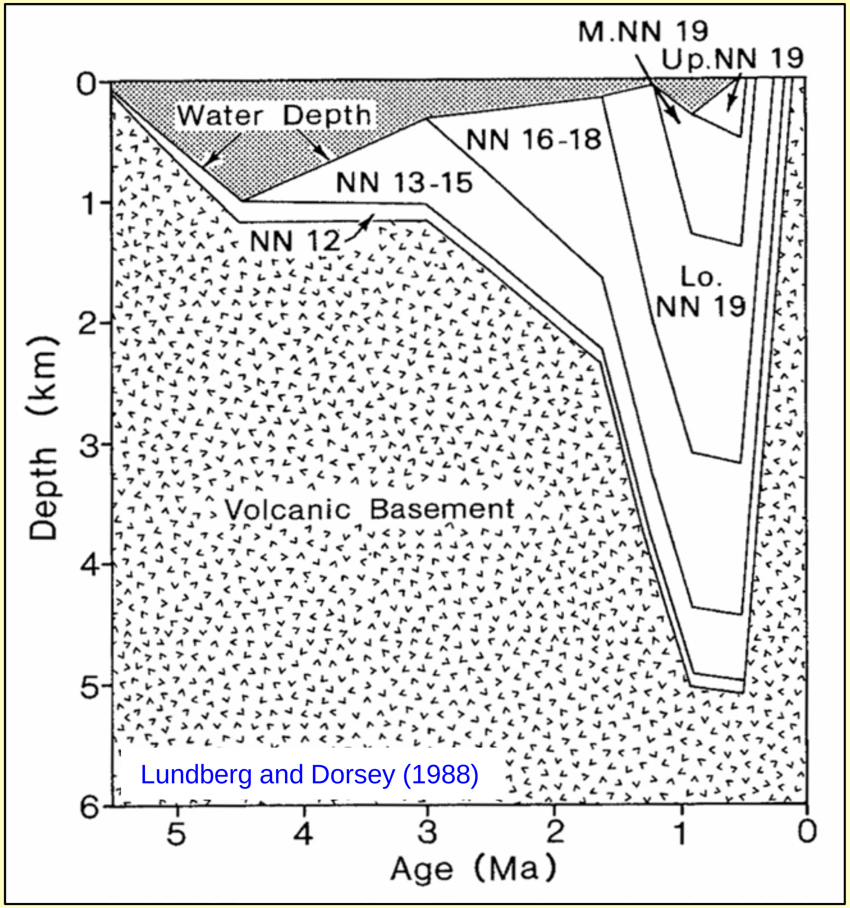


(1) Erosional Unconformity at base: Probable forebulge

(2) Stratal Onlap: Thrust-belt load moved toward basin

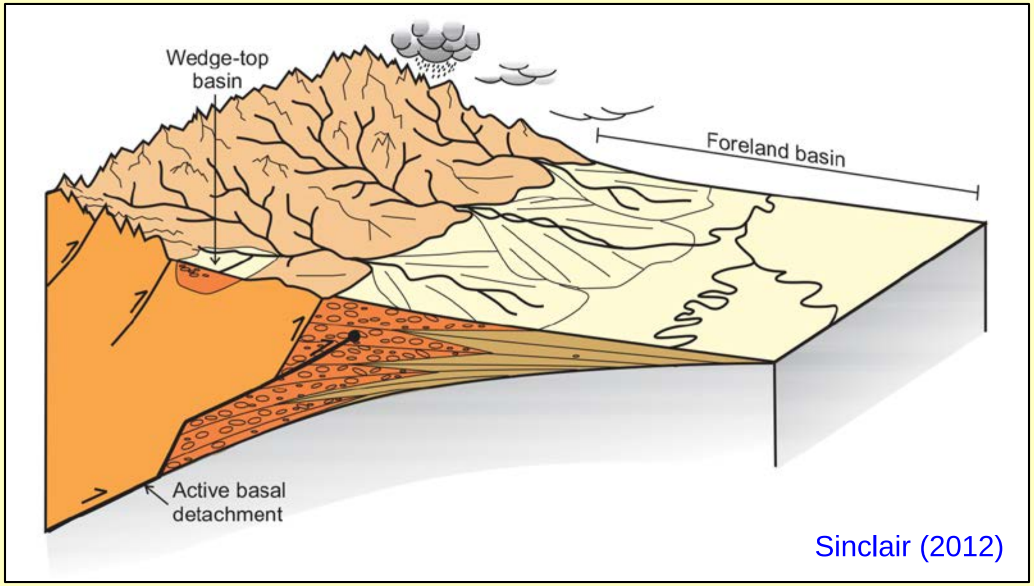
(3) Subsidence: Started slow, accelerated … deep!

(4) Abrupt Uplift at End: Basin incorporated into orogen



Lundberg and Dorsey (1988)

Eastern Collisional Basin – Formed and Evolved as a Marine Foredeep

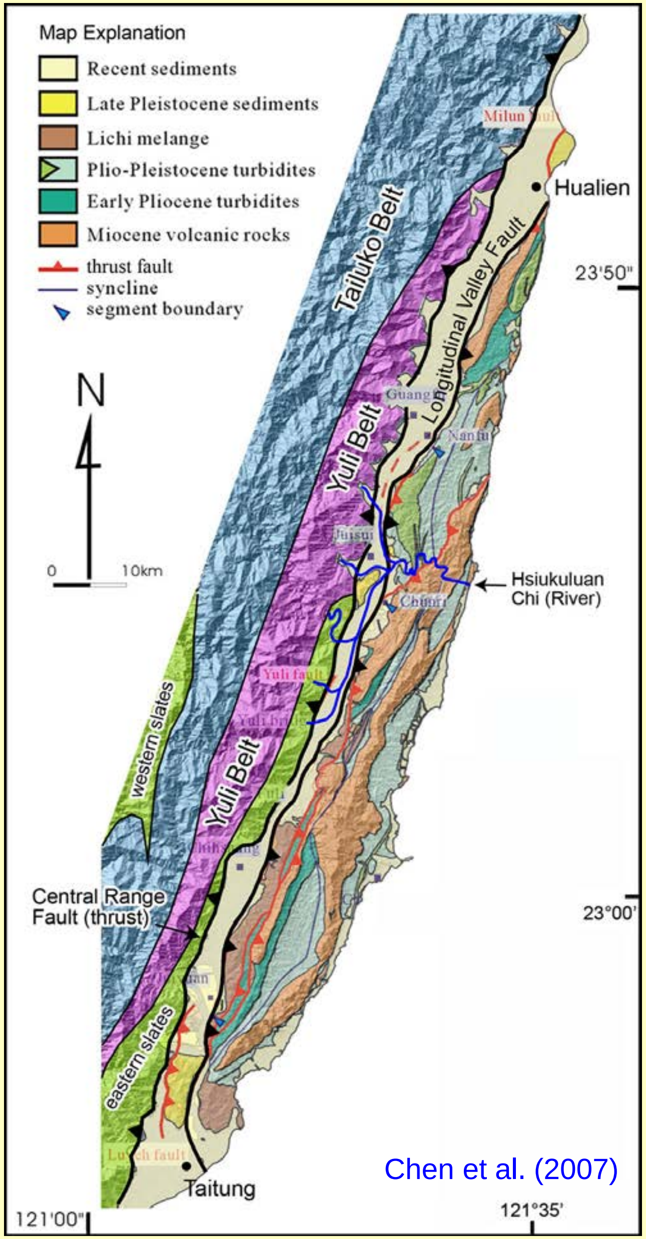


Sinclair (2012)


East Taiwan Coastal Range

	Predicted		Observed
Basin Response to thrust belt evoln	**PRO-foreland basin**	**RETRO-foreland basin**	**Eastern Taiwan RetroWedge Basin**
Stratal Onlap?	Yes	No	**Yes**
Subsidence Starts	Late: ***after*** onset of orogenesis	Early: ***at*** onset of orogenesis	Late: ***after*** onset of orogenesis
Subsidence Evolution	Accelerating, Rapid	Decelerating, Slow	**Accelerating, Rapid**
Steady-state subsidence?	Yes	No	***Uncertain***
Uplift at End?	Yes	No	**Yes**

Eastern Collisional Basin – Formed and Evolved as a Marine Foredeep



In Coastal Range Plio-Pleistocene Sequence:

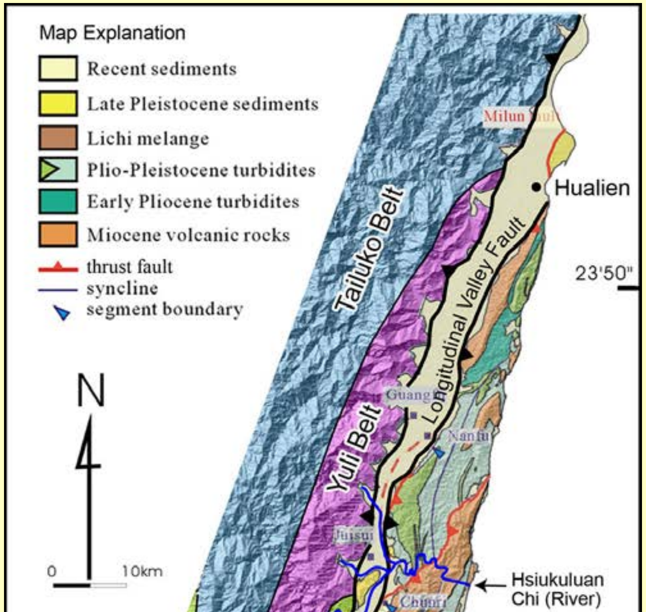
- **Basal Unconformity:** Resembles forebulge unconformity typical of flexural foredeep basins.
- **Basal Mudstone** youngs to east, likely due to migration of thrust load toward basin thru time …
- **Subsidence History: accelerating → rapid**: Typical of migrating flexural foredeep basin
- **Rapid uplift** at end: typical of foredeep basins.

In Eastern Central Range:

- **Yuli Belt** (HP ultramafic) contains Miocene-age rocks of volcanic arc origin: *Luzon arc origin?*
- **Metaconglomerate** in Yuli bel (related to Miocene arc-related Tuluanshan Formation?)

<u>All</u>: suggest large-scale transfer of crust from over-riding plate (PSP) into orogen in past 3-5 Myr.

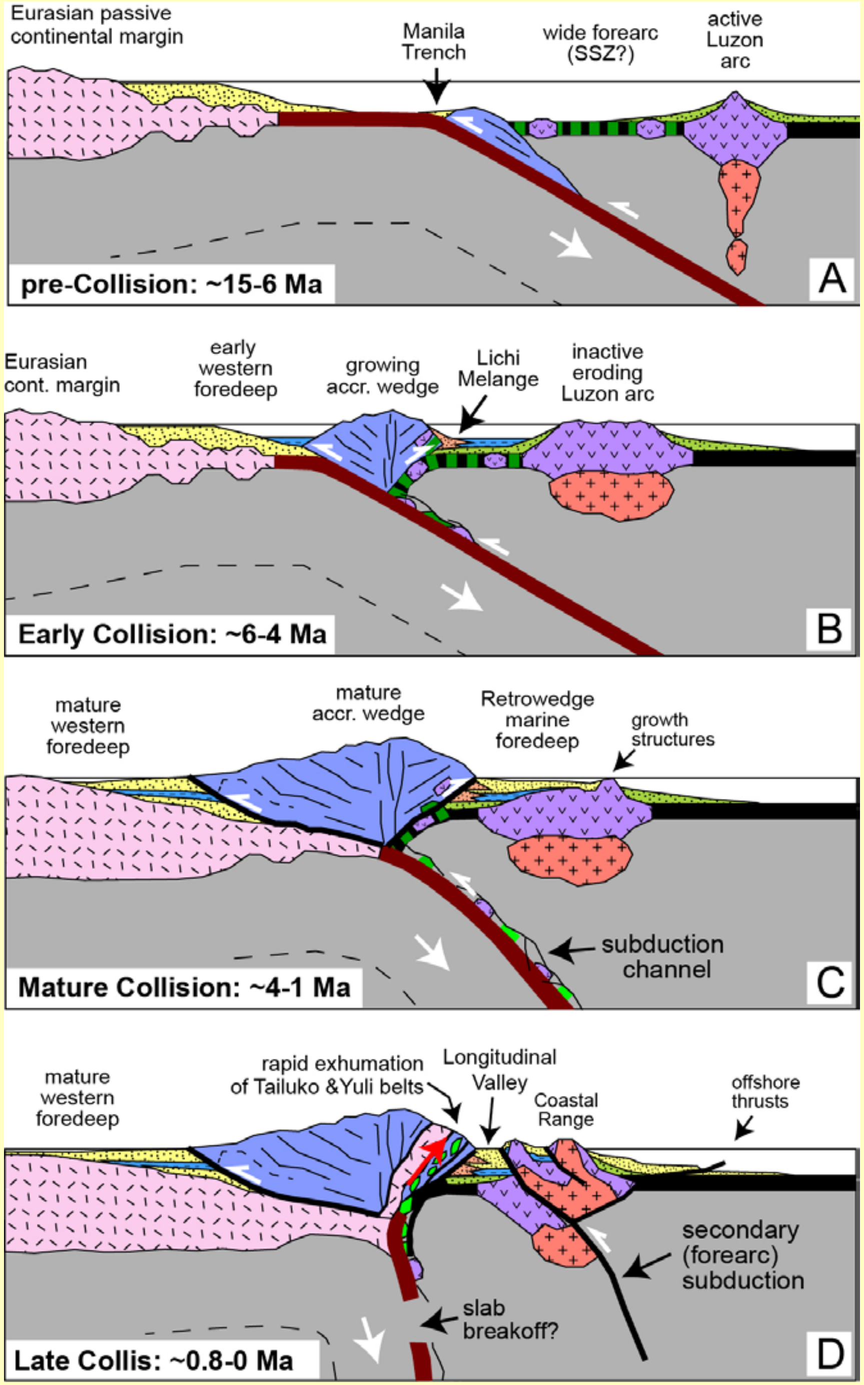
Yuli Belt: Recent Studies & New Ages, Require New Interpretation



- **HP Blueschist:** mafic/ultramafic rx, 50-55 km depth (Tsai et al., 2013; Yui et al., 2014; Keyser et al., 2016)
  15 Ma magmatic zircon in metavolcanics (Chen et al., 2017)
  … possible parent rock is **Miocene Luzon arc ??**
- **Metaconglomerate** clasts: meta-gabbro, -basalt, -andesite? -diabase, marble? Equivalent of Tuluanshan Formation?
- **Suggest large-scale transfer of crust** from the Philippine Sea plate into orogen …
- **How does that work?** Integrate with basinal record …


River gravel sourced from Yuli Belt


Yuli metaconglomerate = Tuluanshan Fm equiv.?



Working Hypothesis

(1) Pre-Collision: ~ 15 – 6 Ma

- Luzon volcanic arc and wide **forearc basin** …
- Possible supra-subduction zone crust (ETO)
- Predates high topography in orogen.

(2) Early Collision: ~ 5 – 4 Ma

- Crustal thickening and uplift/erosion in orogen
- Inactive eroding arc crust, followed by…
- Rapid subsidence in **retro-foredeep basin**
- Lichi Melange olistostromes, turbidites, muds

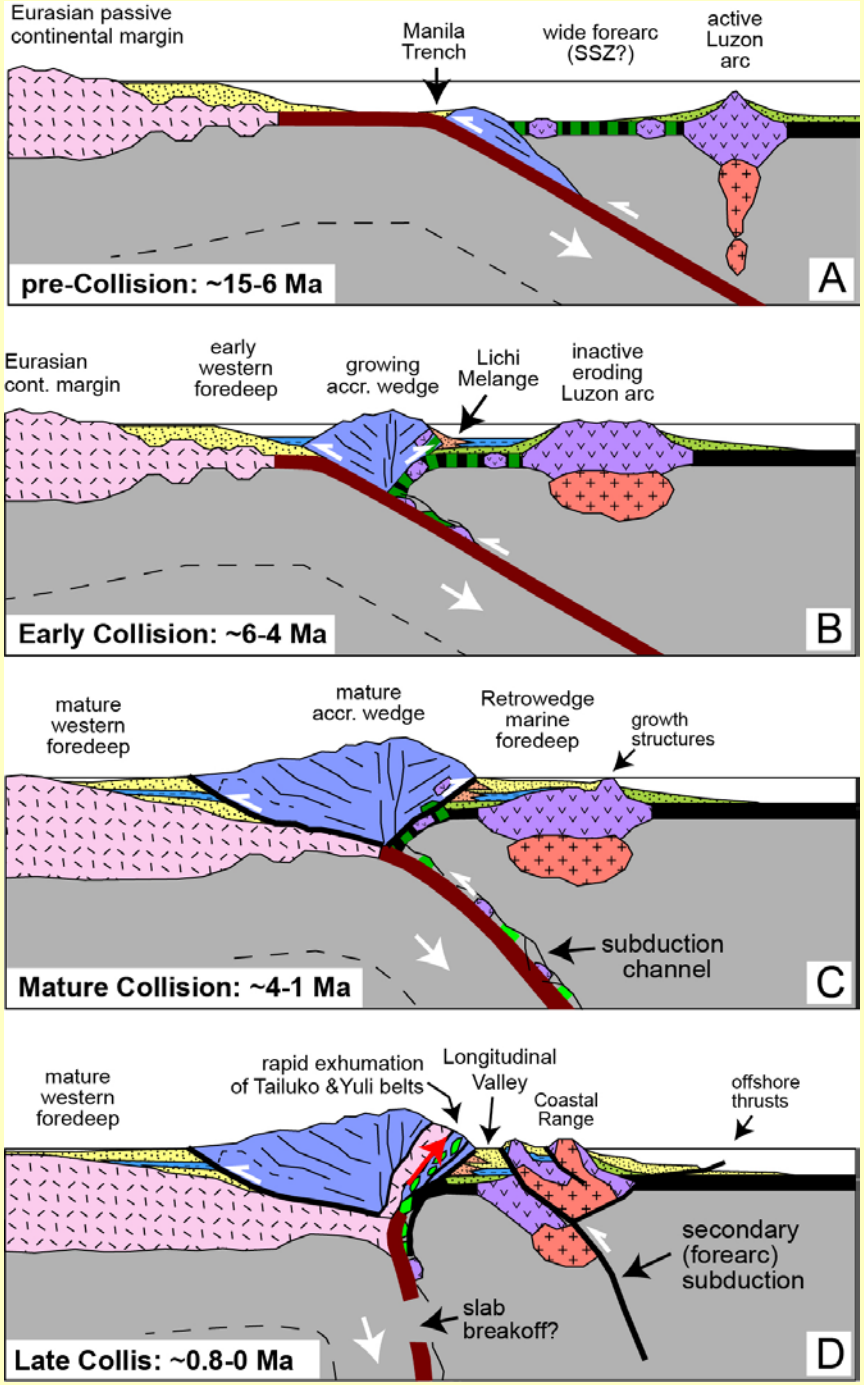
(3) Mature Collision: ~ 4 – 1 Ma

- Flexural subsidence in **retro-foredeep basin**
- Thrust belt converges toward the basin …
- Subduction & exhumation of metamorphic rocks

(4) Late Collision: ~ 0.8 – 0 Ma

- Very rapid exhumation of Yuli belt (HP arc crust, possibly result of slab breakoff ?
- Rapid uplift of Coastal Range **(retro-foredeep)**

Not Steady-State



Deep Time processes: set modern tectonic - topographic architecture of the orogen

Hypotheses to test (collaborative project)

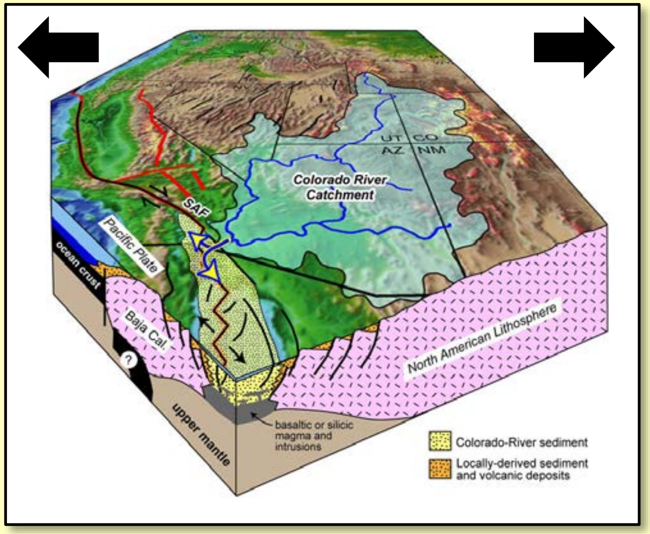
(J.Y. Yen, Y.H. Lee, W.R. Chi, C.S. Horng, M. Grove)

- **Foredeep evolution of Coastal Range:** Convergence between orogen & Luzon arc.
- **Suprasubduction Zone** origin of the ETO
- **Miocene Luzon-Arc** origin of Yuli belt
- **Transfer of over-riding plate** into orogen.
- **Unsteady *simultaneous* exhumation**: very rapid short-lived pulse starting ~1-2 Ma *(Lee et al. 2015; Hsu et al., 2016)*

Basin-forming processes in different tectonic settings

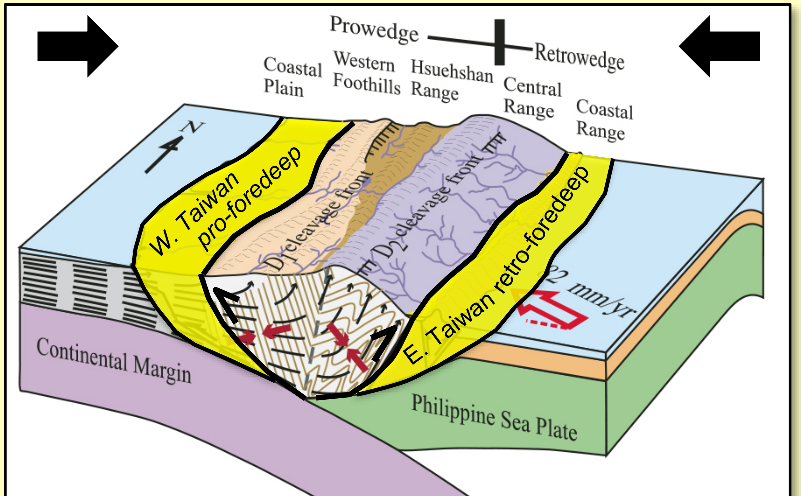
Oblique Continental Rift:

- Extension → Thinning → *Isostatic Subsidence*
- Basins Filled with sediment from ***slowly eroding*** large river source (Colorado River)
- Rapid Subsidence & accumulation of thick syn-extension deposits at active plate boundary
- Plio-Pleistocene (ca. 5-6 Ma) to present
- Feedbacks: Basins, Sediments, Crustal Evolution



Oblique Collisional Orogen:

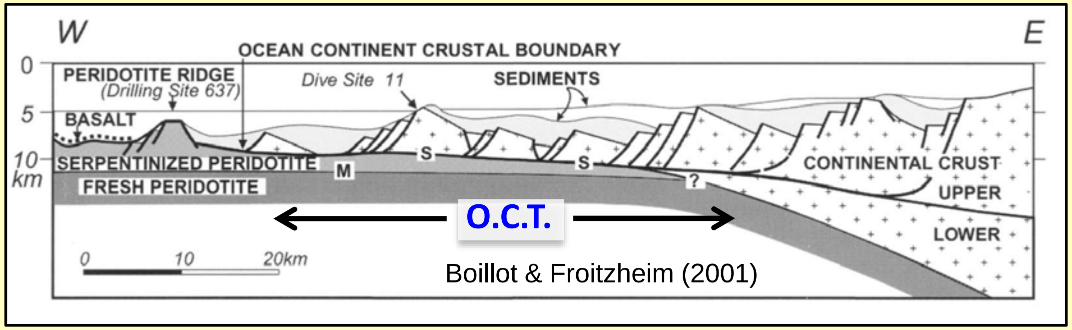
- Shortening → *Thickening* → *Flex. Subsidence*
- Basins Fill with sediment from ***very rapidly eroding*** small, steep river catchments.
- Rapid Subsidence & accumulation of thick syn-orogenic deposits at active plate boundary
- Plio-Pleistocene (ca. 5-6 Ma) to present
- Feedbacks: Basin, Sediments, Crustal Evolution



Fisher et al. (2007)

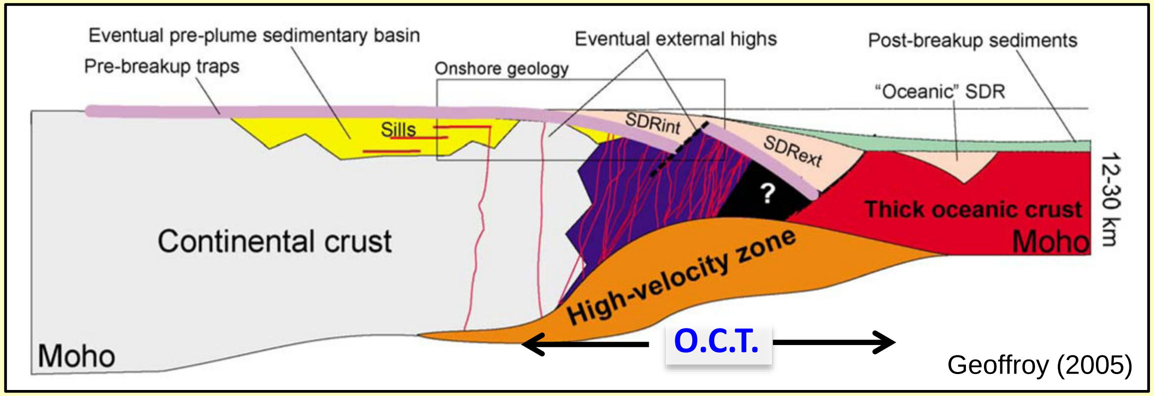
Sedimentary Basins: Insights to deformation, erosion, subsidence processes.

Implications for Rifted Continental Margins



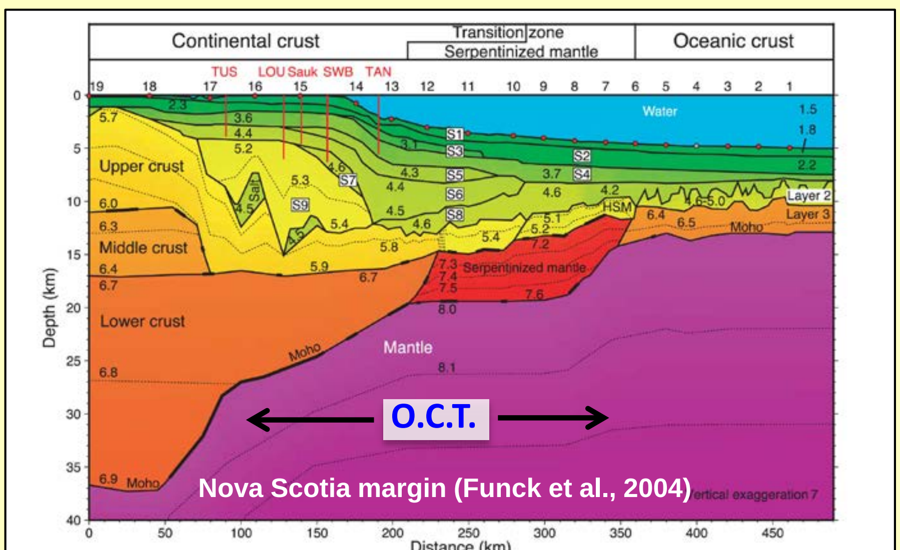
1. Non-Volcanic Margins (Hyper-Extended):

- Thin, magma-starved crust
- Highly extended, core complexes
- Mantle exhumed to near surface



2. Volcanic Rifted Margins:

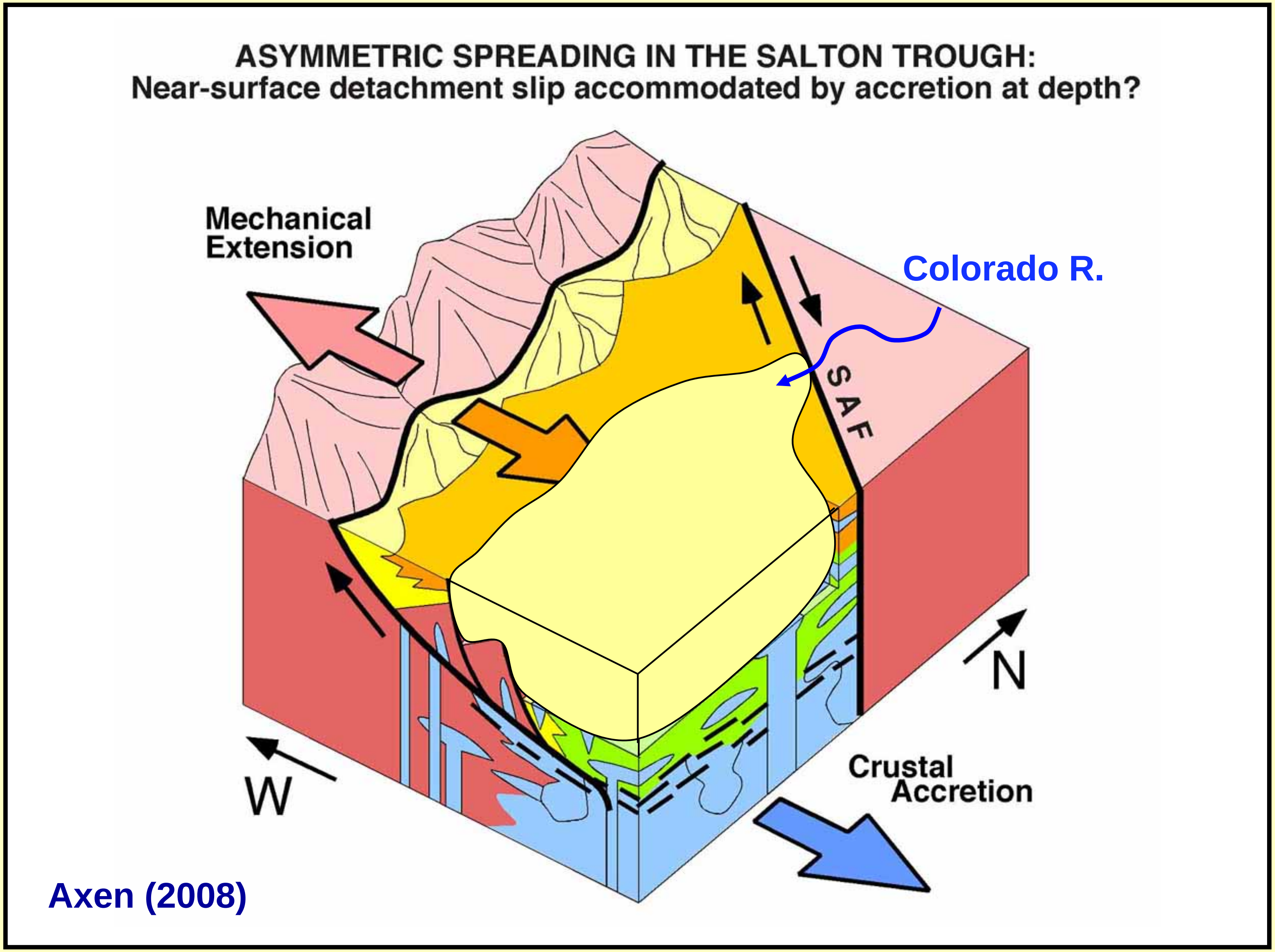
- Thick mafic crust at OCT
- Robust syn-rift magmatism
- **Does not explain thick crust at non-volcanic margins …**



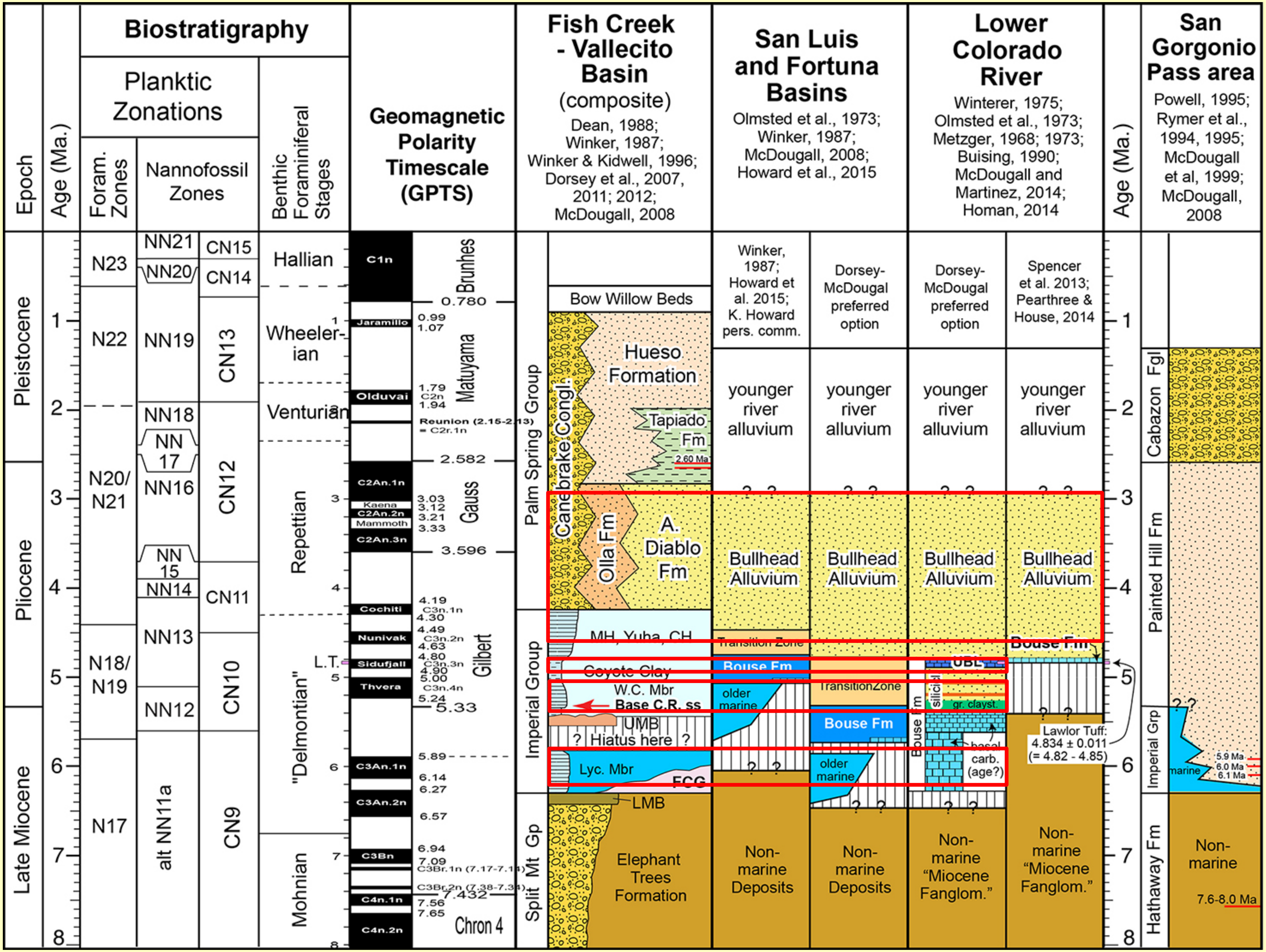
3. Third Type of OCT:

Thick Crust at OCT, *not volcanic*

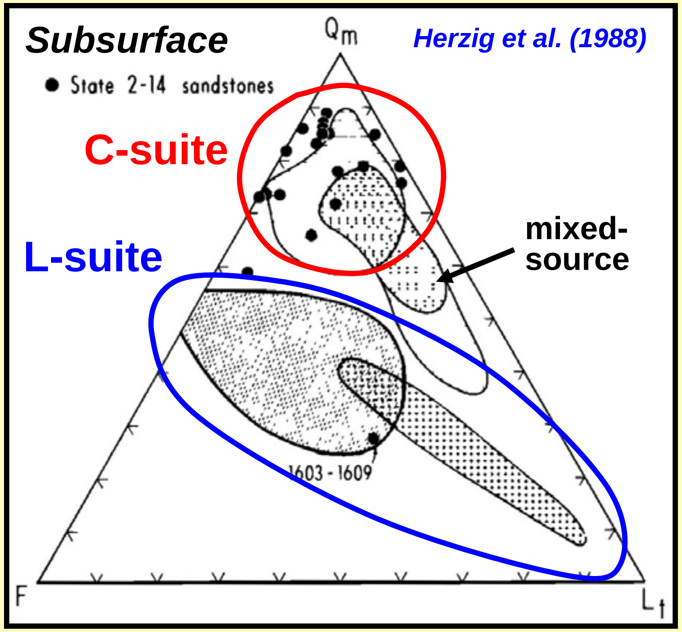
- Intermediate seismic velocities
- Syn-rift sediments with intrusions …
- **Sediment** builds recycled crust by
- **Input from Large Rivers.**
- **Colorado River -** modern example

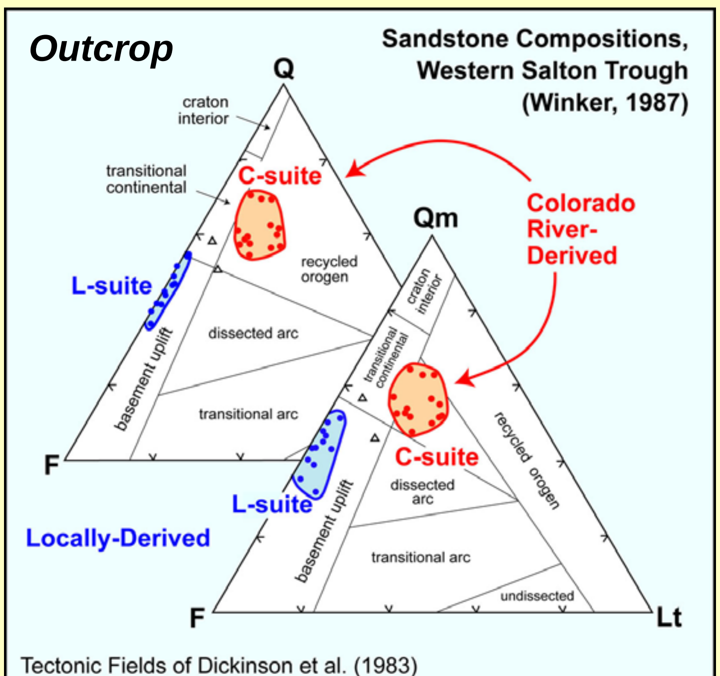


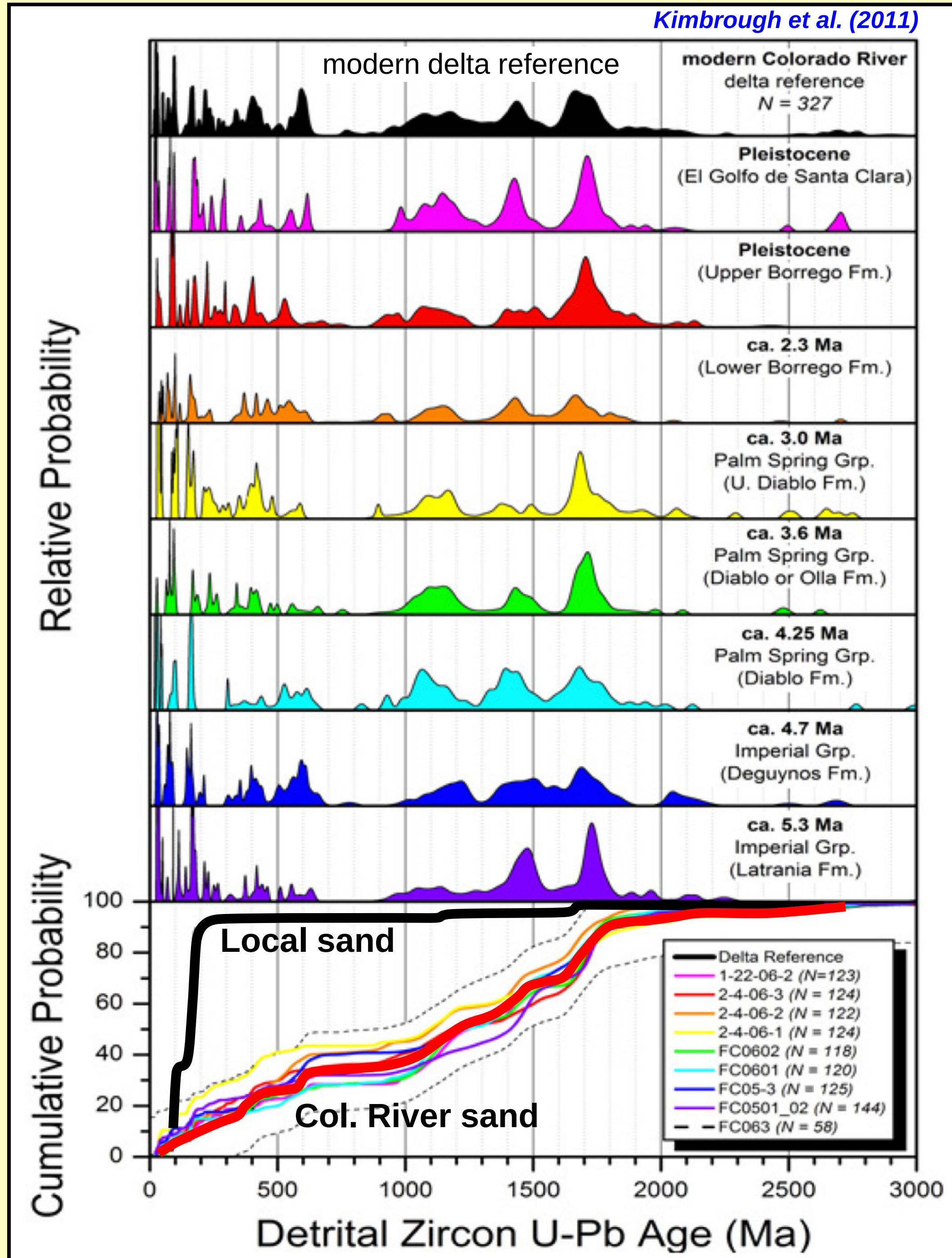
Linked slip on southern SAF and west Salton detachment fault. Space created by lithospheric rupture is filled with basaltic intrusions from below and voluminous sediment input from above (mainly Colorado River).

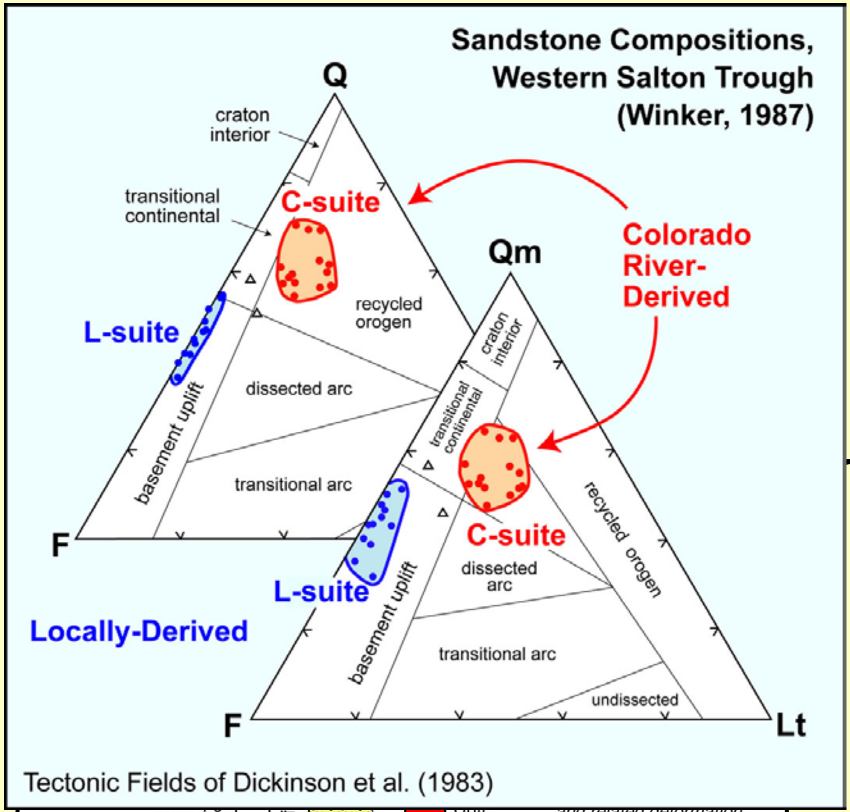

Epoch
Age (Ma.)
Biostratigraphy
Planktic Zonations
Foram. Zones
Nannofossil Zones
Benthic Foraminiferal Stages
Geomagnetic Polarity Timescale (GPTS)
Fish Creek - Vallecito Basin (composite)
Dean, 1988; Winker, 1987; Winker & Kidwell, 1996; Dorsey et al., 2007, 2011; 2012; McDougall, 2008
San Luis and Fortuna Basins
Olmsted et al., 1973; Winker, 1987; McDougall, 2008; Howard et al., 2015
Lower Colorado River
Winterer, 1975; Olmsted et al., 1973; Metzger, 1968; 1973; Buising, 1990; McDougall and Martinez, 2014; Homan, 2014
Age (Ma.)
San Gorgonio Pass area
Powell, 1995; Rymer et al., 1994, 1995; McDougall et al, 1999; McDougall, 2008
Pleistocene
Pliocene
Late Miocene
N23
N22
N20/ N21
N18/ N19
N17
NN21
NN20
NN19
NN18
NN 17
NN16
NN 15
NN14
NN13
NN12
alt NN11a
CN15
CN14
CN13
CN12
CN11
CN10
CN9
Hallian
Wheeler-ian
Venturian
Repettian
"Delmontian"
Mohnian
L.T.
C1n
Brunhes
0.780
Jaramillo
0.99
1.07
Matuyama
Olduvai
1.79
C2n
1.94
Reunion (2.15-2.13) = C2r.1n
2.582
C2An.1n
Kaena
C2An.2n
Mammoth
C2An.3n
3.03
3.12
3.21
3.33
Gauss
3.596
Cochiti
4.19
C3n.1n
4.30
Nunivak
4.49
C3n.2n
4.63
Sidufjall
4.80
C3n.3n
4.90
5.00
Thvera
C3n.4n
5.24
5.33
Gilbert
C3An.1n
5.89
6.14
6.27
C3An.2n
6.57
C3Bn
6.94
7.09
C3Br.1n (7.17-7.14)
C3Br.2n (7.38-7.34)
7.432
C4n.1n
7.56
7.65
C4n.2n
Chron 4
Palm Spring Group
Imperial Group
Split Mt Gp
Bow Willow Beds
Canebrake Congl.
Hueso Formation
Tapiado Fm
2.60 Ma
Olla Fm
A. Diablo Fm
MH, Yuha, CH
Coyote Clay
W.C. Mbr
Base C.R. ss
UMB
? Hiatus here ?
Lyc. Mbr
FCG
LMB
Elephant Trees Formation
Winker, 1987; Howard et al. 2015; K. Howard pers. comm.
Dorsey-McDougal preferred option
Dorsey-McDougal preferred option
Spencer et al. 2013; Pearthree & House, 2014
younger river alluvium
younger river alluvium
younger river alluvium
younger river alluvium
Bullhead Alluvium
Bullhead Alluvium
Bullhead Alluvium
Bullhead Alluvium
Transition Zone
Bouse Fm
older marine
TransitionZone
Bouse Fm
older marine
Non-marine Deposits
Non-marine Deposits
UBL
siliciclastic
gr. clayst.
Bouse Fm
basal carb. (age?)
Non-marine "Miocene Fanglom."
Bouse Fm
Lawlor Tuff: 4.834 ± 0.011 (= 4.82 - 4.85)
Non-marine "Miocene Fanglom."
Cabazon Fgl
Painted Hill Fm
Imperial Grp
Hathaway Fm
marine
5.9 Ma
6.0 Ma
6.1 Ma
Non-marine
7.6-8.0 Ma

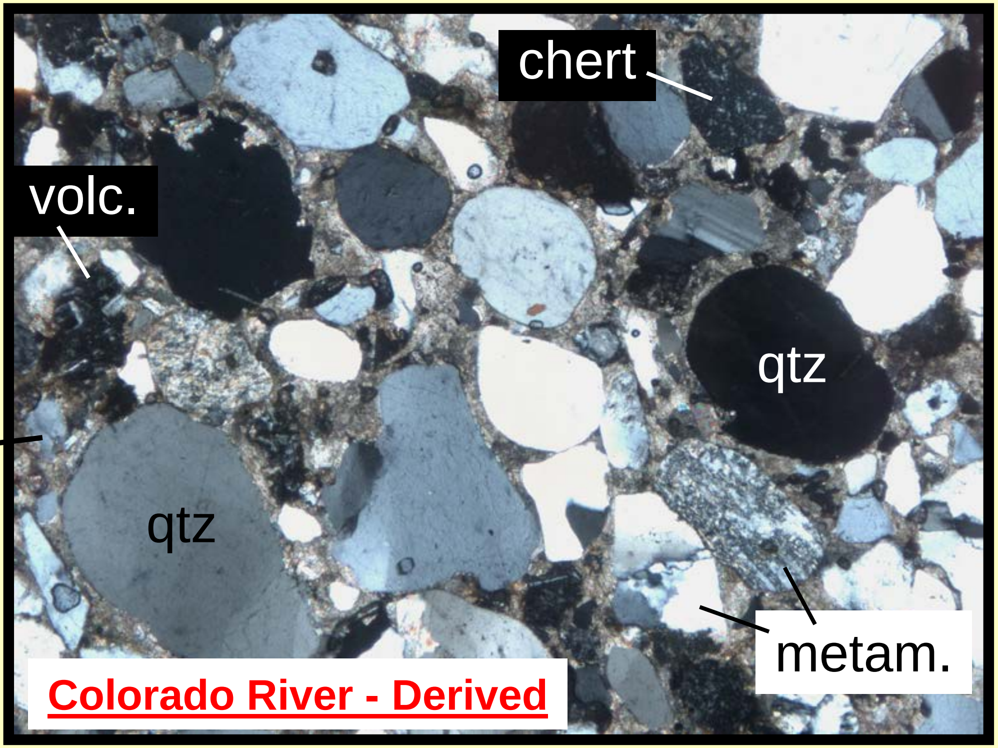
Sand Composition

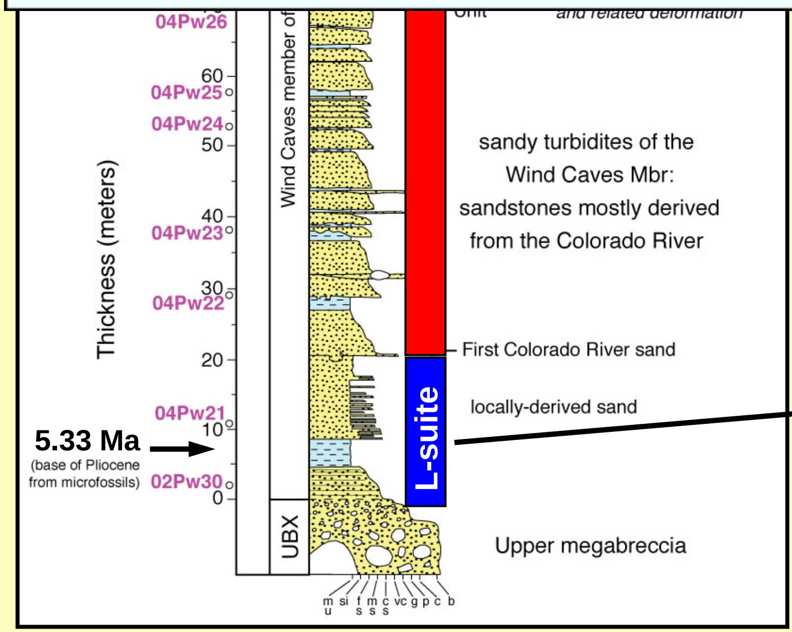


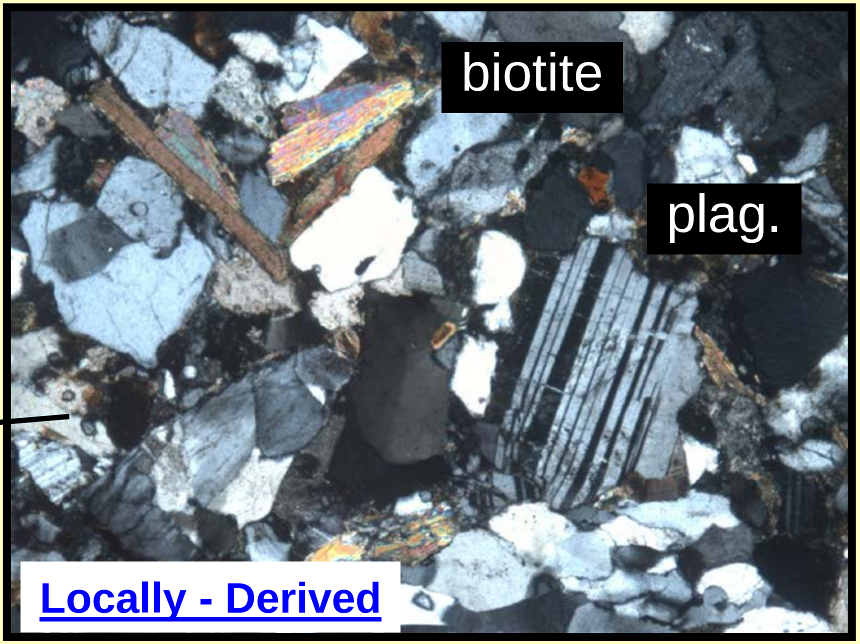


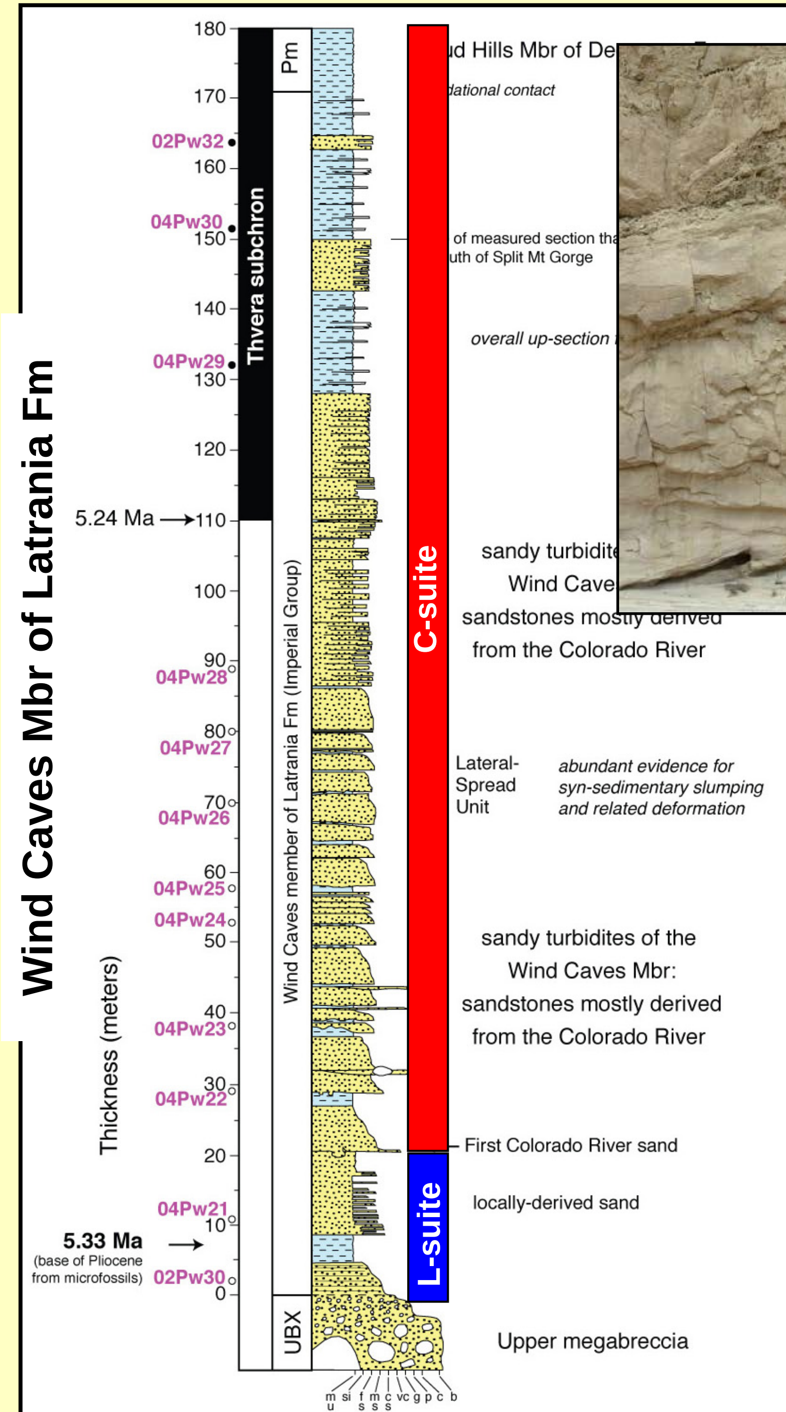



Sandstone Compositions,
Western Salton Trough
(Winker, 1987)
Q
craton interior
transitional continental
C-suite
recycled orogen
L-suite
dissected arc
transitional arc
basement uplift
F
Colorado River-Derived
Qm
craton interior
transitional continental
recycled orogen
C-suite
dissected arc
transitional arc
undissected
basement uplift
L-suite
Locally-Derived
F
Lt
Tectonic Fields of Dickinson et al. (1983)


chert
volc.
qtz
qtz
metam.
Colorado River - Derived


04Pw26
04Pw25
04Pw24
04Pw23
04Pw22
04Pw21
02Pw30
Thickness (meters)
60
50
40
30
20
10
0
5.33 Ma
(base of Pliocene from microfossils)
Wind Caves member of
UBX
L-suite
sandy turbidites of the Wind Caves Mbr: sandstones mostly derived from the Colorado River
First Colorado River sand
locally-derived sand
Upper megabreccia


biotite
plag.
Locally - Derived



Wind Caves Mbr of Latrania Fm
Thickness (meters)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
02Pw32
04Pw30
04Pw29
04Pw28
04Pw27
04Pw26
04Pw25
04Pw24
04Pw23
04Pw22
04Pw21
02Pw30
5.24 Ma
5.33 Ma
(base of Pliocene from microfossils)
Thvera subchron
Pm
Wind Caves member of Latrania Fm (Imperial Group)
UBX
C-suite
L-suite
ud Hills Mbr of De
dational contact
of measured section tha
uth of Split Mt Gorge
overall up-section
sandy turbidite
Wind Cave
sandstones mostly derived
from the Colorado River
Lateral-Spread Unit
abundant evidence for syn-sedimentary slumping and related deformation
sandy turbidites of the Wind Caves Mbr: sandstones mostly derived from the Colorado River
First Colorado River sand
locally-derived sand
Upper megabreccia
m u si f s m s c s vc g p c b

Colorado River-derived turbidites

Locally derived turbidites

The Taiwan Observatory, "Collaboratory":

"Feedbacks Among Climate Erosion and Tectonics"

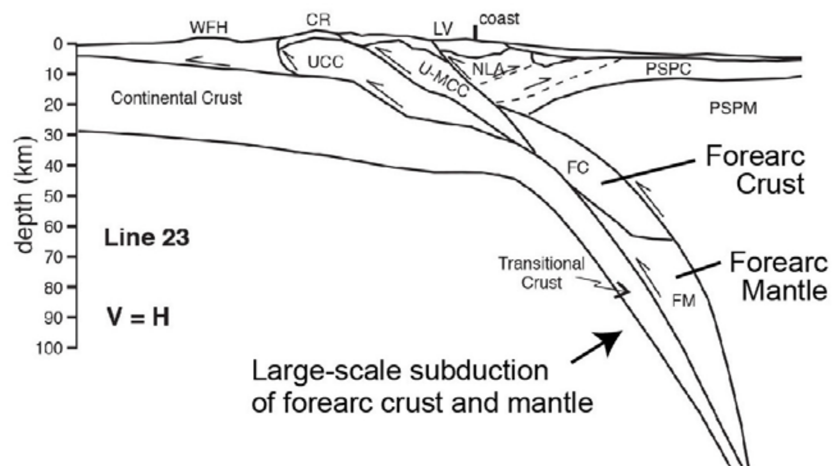
FACET Workshop I - May 2015

- Relatively simple orogen: compact, excellent access
- Rapid forcing: tectonic and surface processes
- Onshore-Offshore linkages: MARGINS-type focus site
- High quality scientists, strong collaborations
- Excellent Infrastructure (geodesy, seismology, hydrology): earthquakes, landslides, river discharge, morphology, etc.
- Also provides insight into …

- Deep Time processes at *1-5 Myr timescale …*

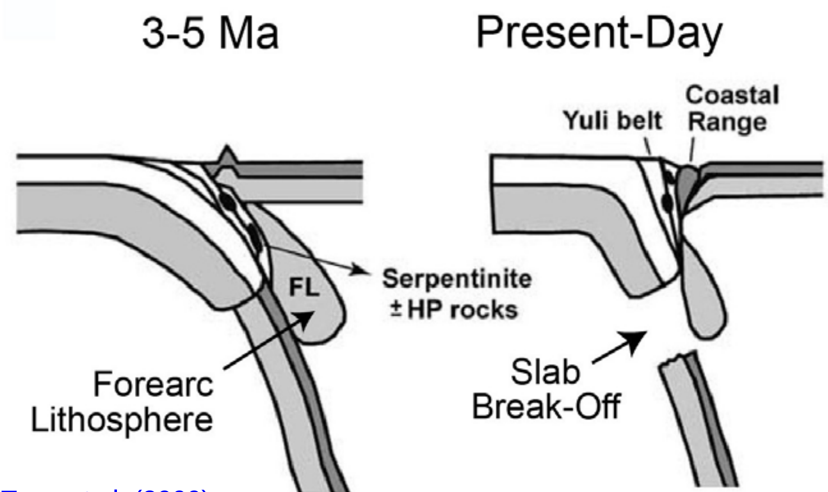
- Control Tectonic-Topographic Architecture of orogen

Tectonic Models for Taiwan and Eastern Retro-wedge Domain



McIntosh et al. (2005)

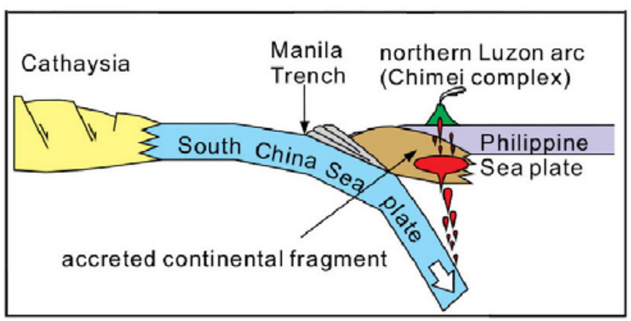
subduction channel

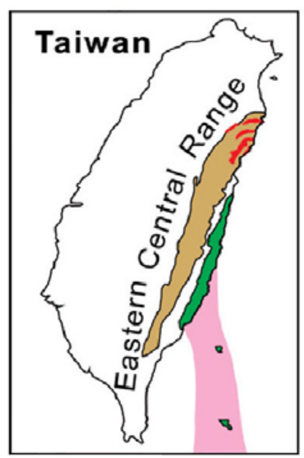


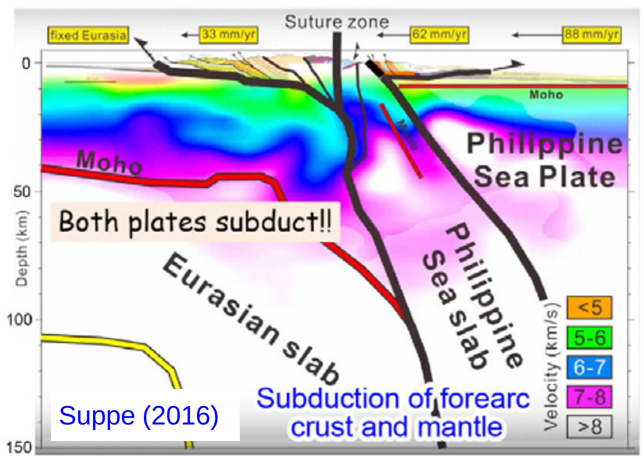
Teng et al. (2000);
Yui et al. (2014)

Slab breakoff, very rapid exhumation

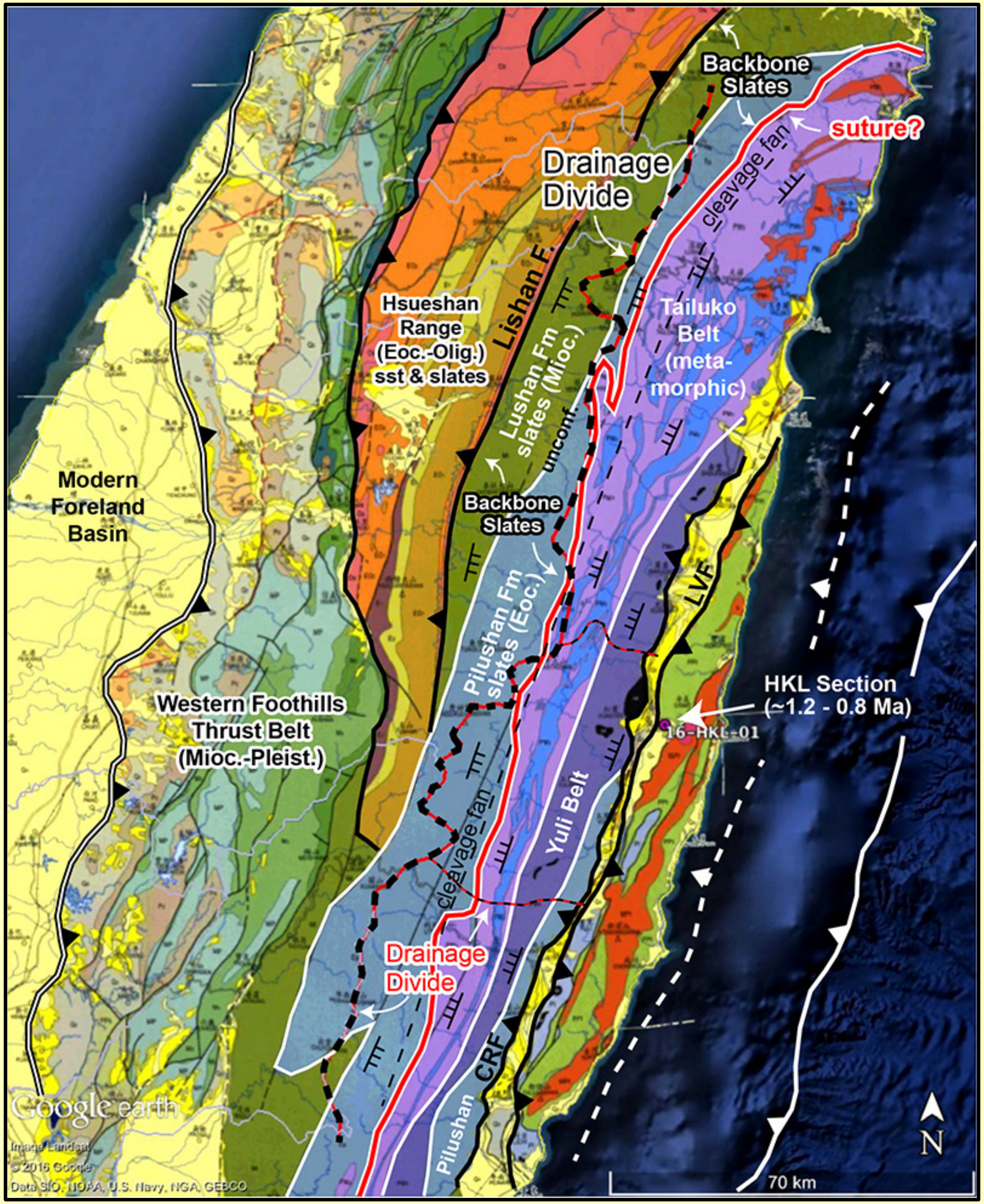
Far-traveled microcontinental fragment? (Shao et al., 2015)







Suppe (2016)

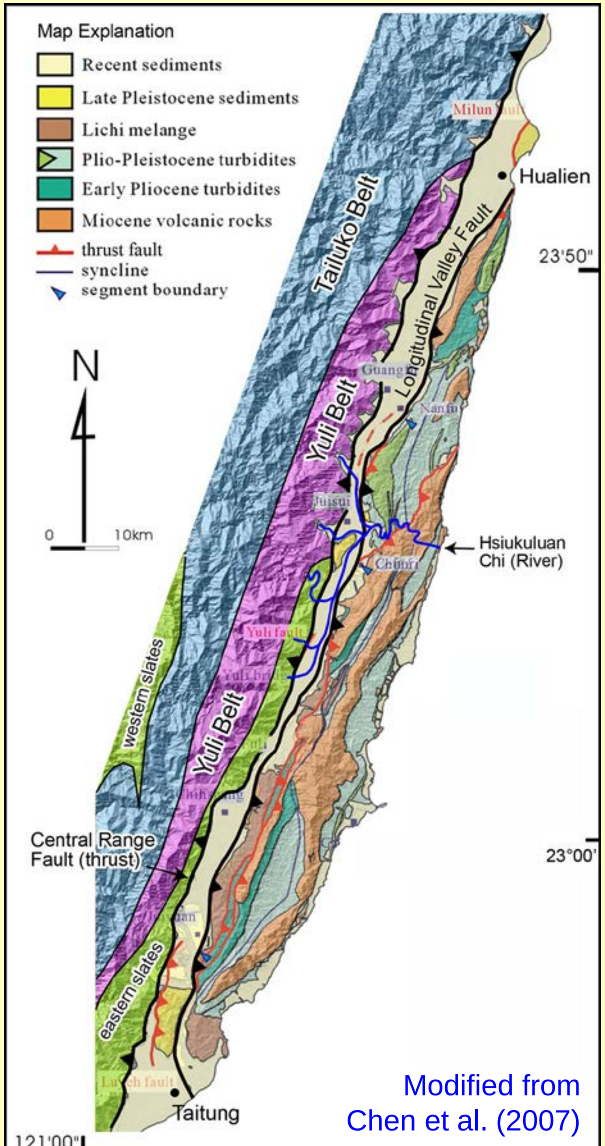


Tectonics of Eastern Taiwan

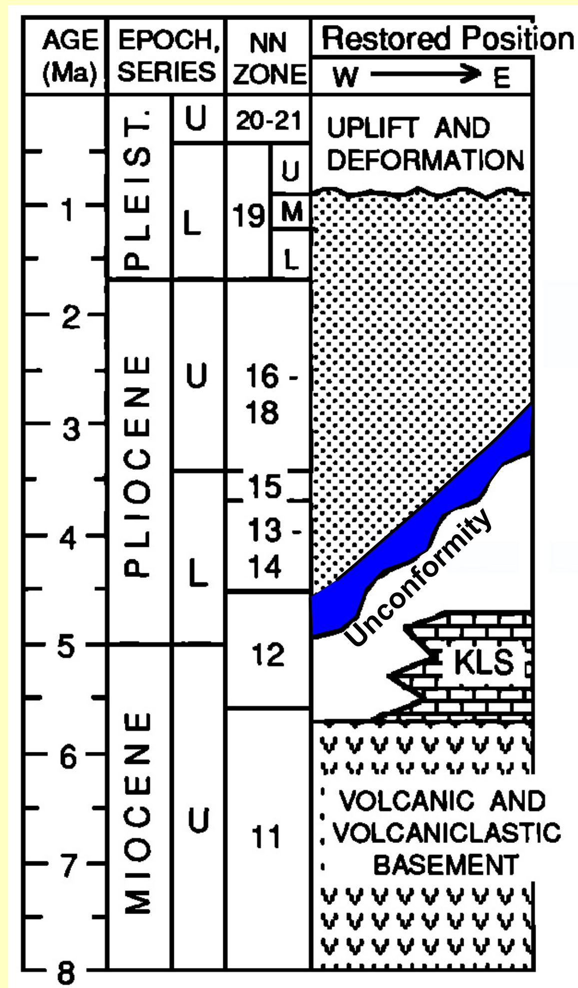
- **Tailuko Belt: (1)** Eurasian continent (e.g., McIntosh et al., 2013); **or** **(2)** Far traveled micro-continent fragment (Shao et al., 2015) ?
- **Yuli Belt:** Miocene *arc-related rocks* exhumed from deep subduction zone (e.g., Chen et al., 2017).
- **Lichi Melange:** blocks of meta-sst, Luzon arc, and ophiolite (ETO) … *Supra-subduction zone setting?*
- **Collisional Basin** (Coastal Range) Subsided rapidly, migrated toward thrust load: marine foredeep basin.
- **Observations Suggest:**
  - *Large (~100 km?) Shortening* between Luzon arc and orogen
  - Erosion of Luzon arc 4-6 Ma (no modern analog for this)
  - Crust of Philippine Sea Plate and Luzon arc transferred into eastern part of thrust belt
  - Very rapid exhumation ~1-2 Ma: transient, not steady

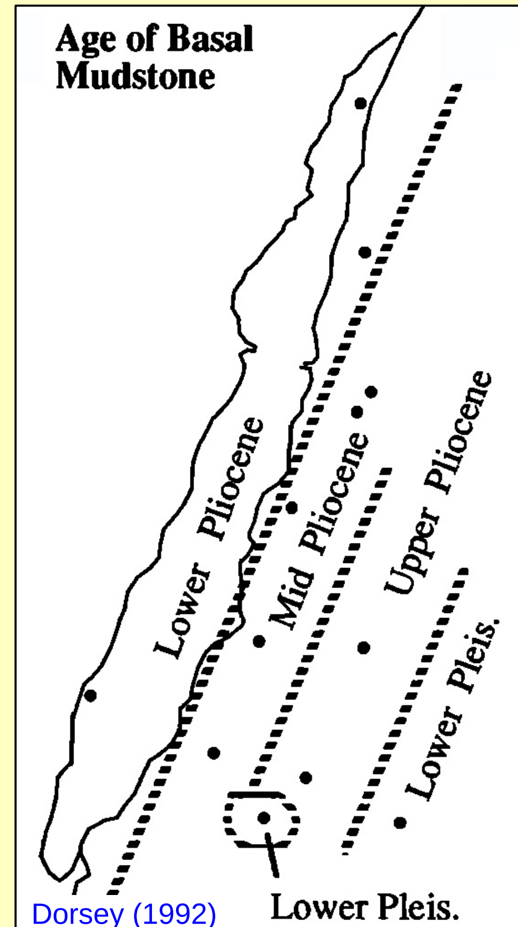
Are Taiwan Basins Consistent with Predictions of Doubly-Vergent Wedge Model ?

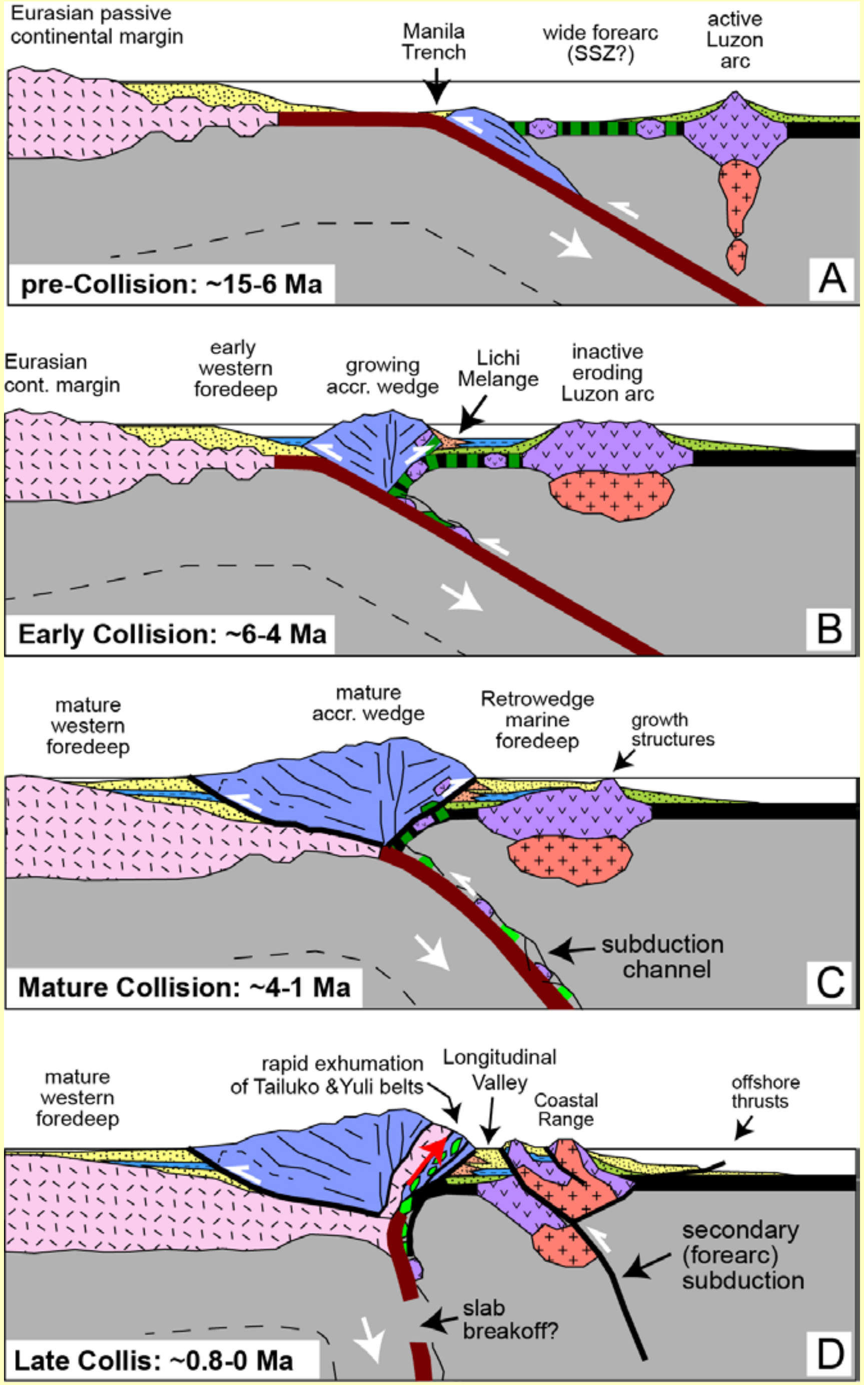
- **In the Eastern Retrowedge and Collisional Basin: NO**



- Erosional Unconformity at base – probable forebulge of migrating flexural marine foredeep basin.
- Stratal Onlap: Eastward younging basal mudstone.







Working Hypothesis

Eastern Retrowedge Basin:

(1) Erosional Unconformity at base (forebulge unconf.)

(2) Stratal Onlap: Basin moved toward thrust-belt load

(3) Subsidence accelerated, abrupt rapid uplift at end

Lichi Melange:

(1) Blocks of sedimentary, volcanic, & mafic/ultramafic rocks mixed in chaotic melange

(2) Rounded clasts of low-grade metasandstone

(3) Large submarine slumps & shear fabrics

(4) East Taiwan Ophilite: origin debated, need new data

Yuli Belt:

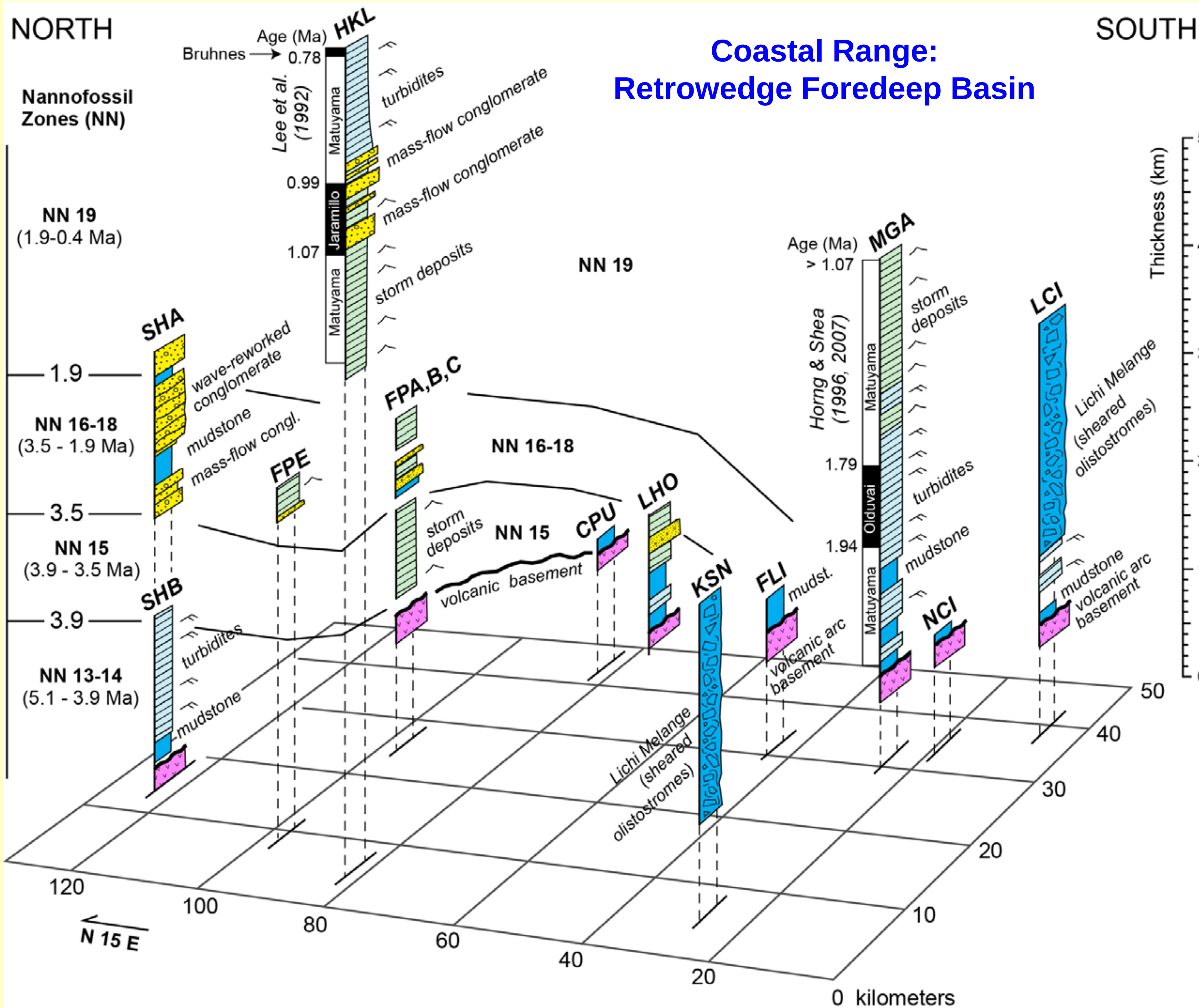
(1) Miocene xlization age and volcanic-arc origin of mafic/ultramafic blocks. Recent discovery.

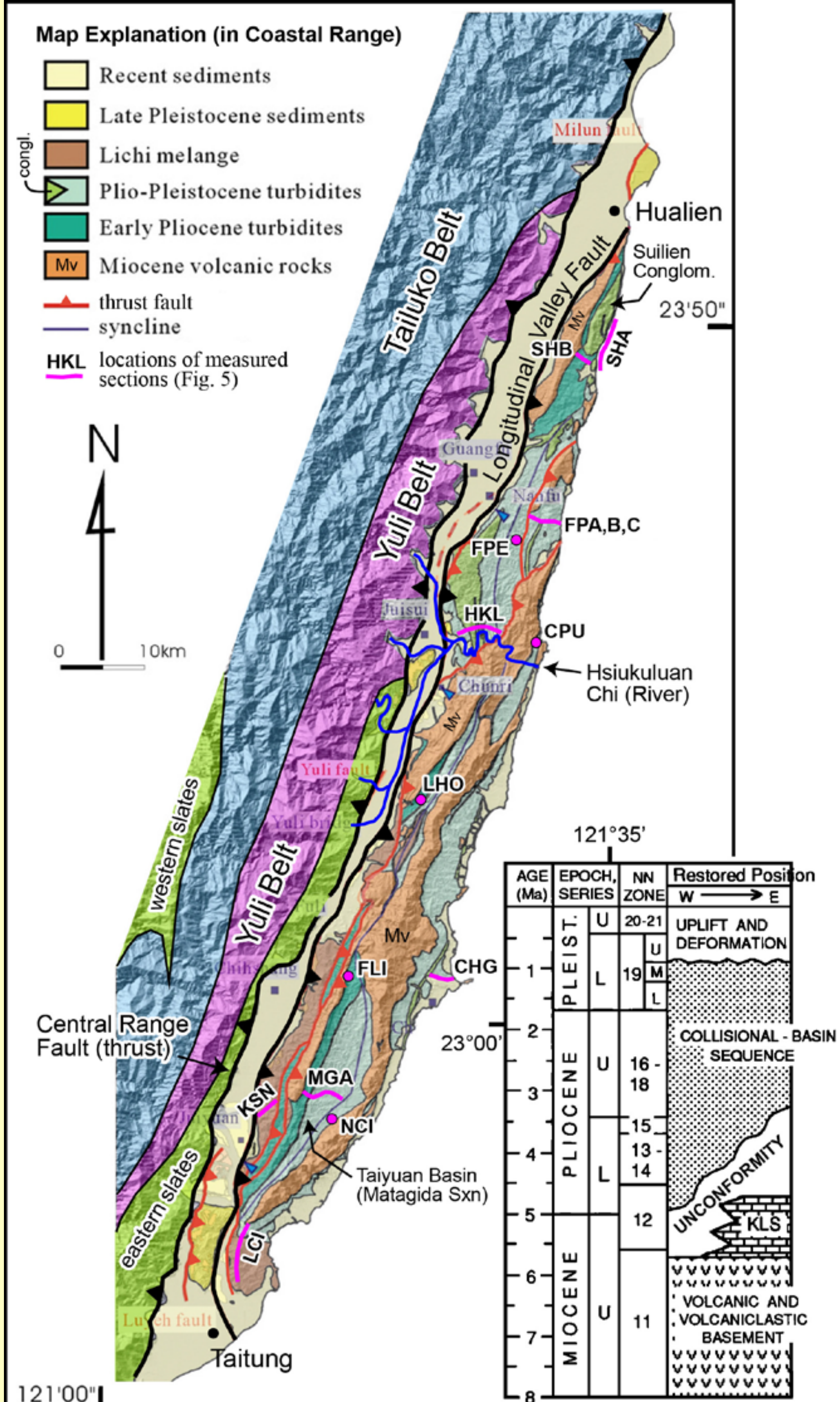
(2) Prograde HP metam. facies → retrograde phase

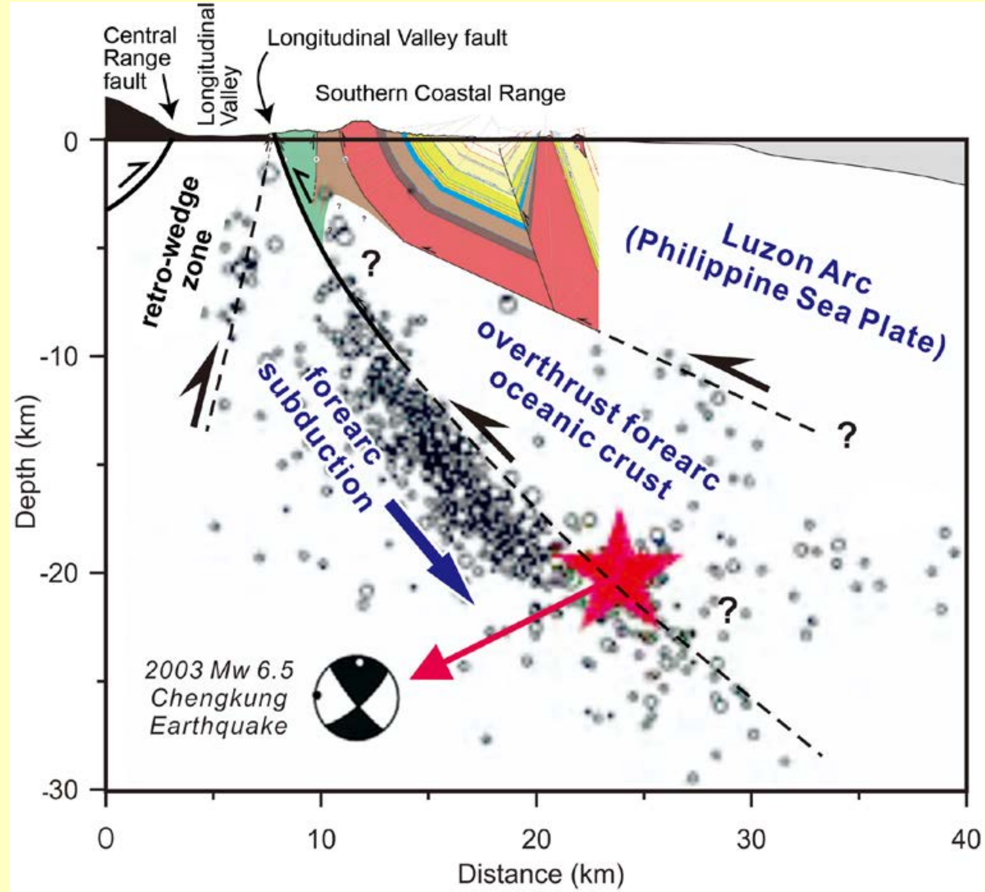
(3) Very Rapid Exhumation in past 1-2 Ma.

Not Steady-State

Coastal Range: Retrowedge Foredeep Basin




Map Explanation (in Coastal Range)
Recent sediments
Late Pleistocene sediments
Lichi melange
congl.
Plio-Pleistocene turbidites
Early Pliocene turbidites
Mv Miocene volcanic rocks
thrust fault
syncline
HKL locations of measured sections (Fig. 5)
N
0
10km
Tailuko Belt
Yuli Belt
Longitudinal Valley Fault
Milun fault
Hualien
Suilien Conglom.
23'50"
SHB
SHA
FPA,B,C
FPE
HKL
CPU
Hsiukuluan Chi (River)
Yuli fault
LHO
western slates
eastern slates
Mv
CHG
FLI
Central Range Fault (thrust)
KSN
MGA
NCI
Taiyuan Basin (Matagida Sxn)
LCI
Taitung
121'00"
121°35'
23°00'
AGE (Ma)
EPOCH, SERIES
NN ZONE
Restored Position W → E
PLEIST.
PLIOCENE
MIOCENE
U
L
20-21
19
U
M
16 - 18
15
13 - 14
12
11
UPLIFT AND DEFORMATION
COLLISIONAL - BASIN SEQUENCE
UNCONFORMITY
KLS
VOLCANIC AND VOLCANICLASTIC BASEMENT
1
2
3
4
5
6
7
8


Central Range fault
Longitudinal Valley
Longitudinal Valley fault
Southern Coastal Range
retro-wedge zone
Luzon Arc (Philippine Sea Plate)
overthrust forearc oceanic crust
forearc subduction
?
2003 Mw 6.5 Chengkung Earthquake
Depth (km)
0
-10
-20
-30
Distance (km)
0
10
20
30
40

Sedimentation in Continental Rifts and Collisional Orogens: Insights from Southern California and Eastern Taiwan

Rebecca Dorsey *– University of Oregon*

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科技部
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National Science Foundation

University of Oregon

And: Yuan-Hsi Lee (NCCU); Jiun-Yee Yen (NDHU); Wen-Rong Chi (NCU); Chih-Tung Chen (NCU)

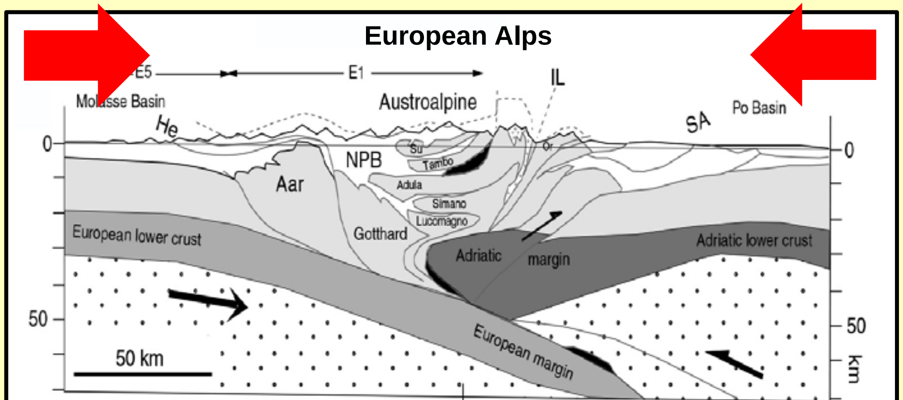
View north along Beinan Chi: active plate boundary

Sedimentation in Continental Rifts and Collisional Orogens: Insights from Southern California and Eastern Taiwan

Rebecca Dorsey – University of Oregon

The Wilson Cycle: Classic concept in plate tectonics …

Collisonal Mountain Belts:
Produced by CONVERGENCE



Pfiffner et al. (2002)

Rifted Continental Margins:
Produced by EXTENSION

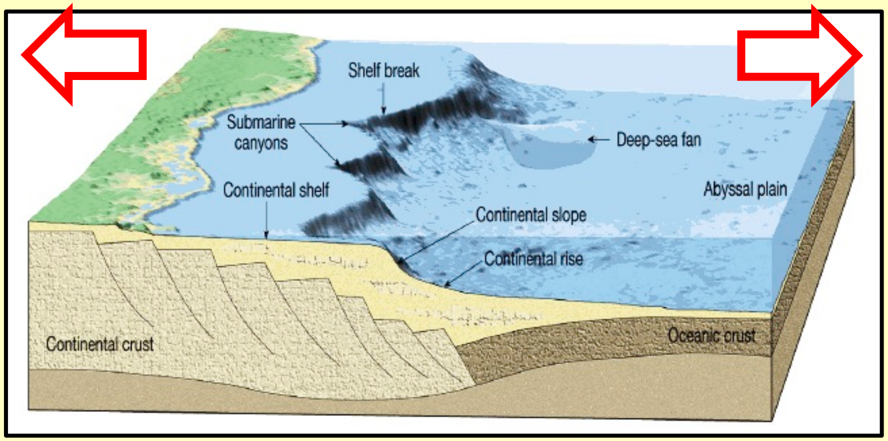
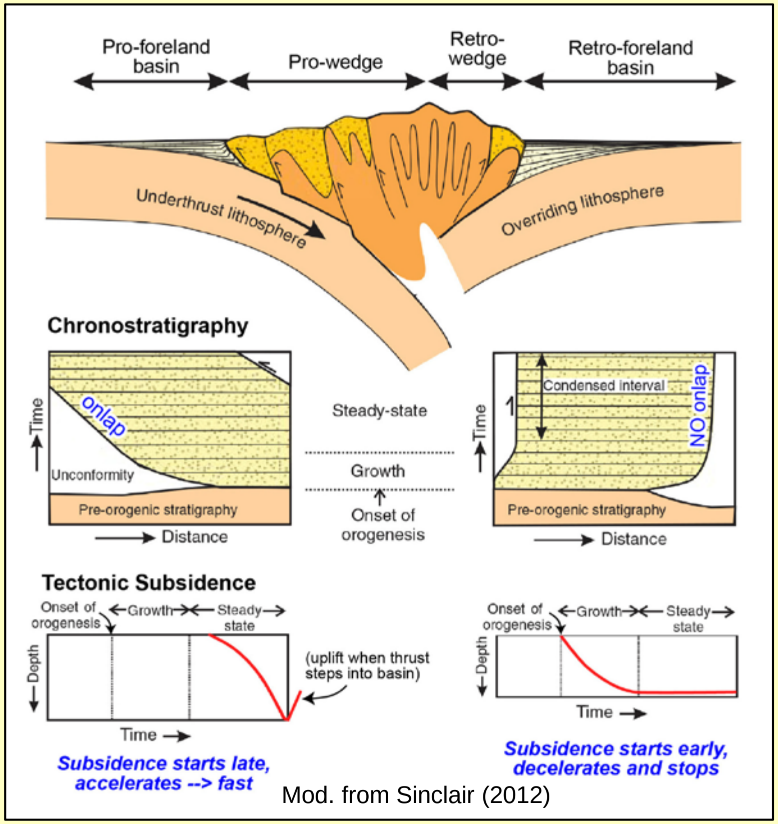


Plate boundaries *and dominant basin type* change through geologic time.

Predictions of the Doubly-Vergent Wedge Model for *Sedimentary Basins*



Mod. from Sinclair (2012)

Pro-foreland basin (FLEXURAL SUBSIDENCE):

- ***Thrust belt migrates toward basin*** …
- Subsidence driven by subduction of plate beneath the orogen: starts slow, accelerates → fast.
- Abrupt change to uplift when basin is incorporated into the converging-migrating thrust belt.

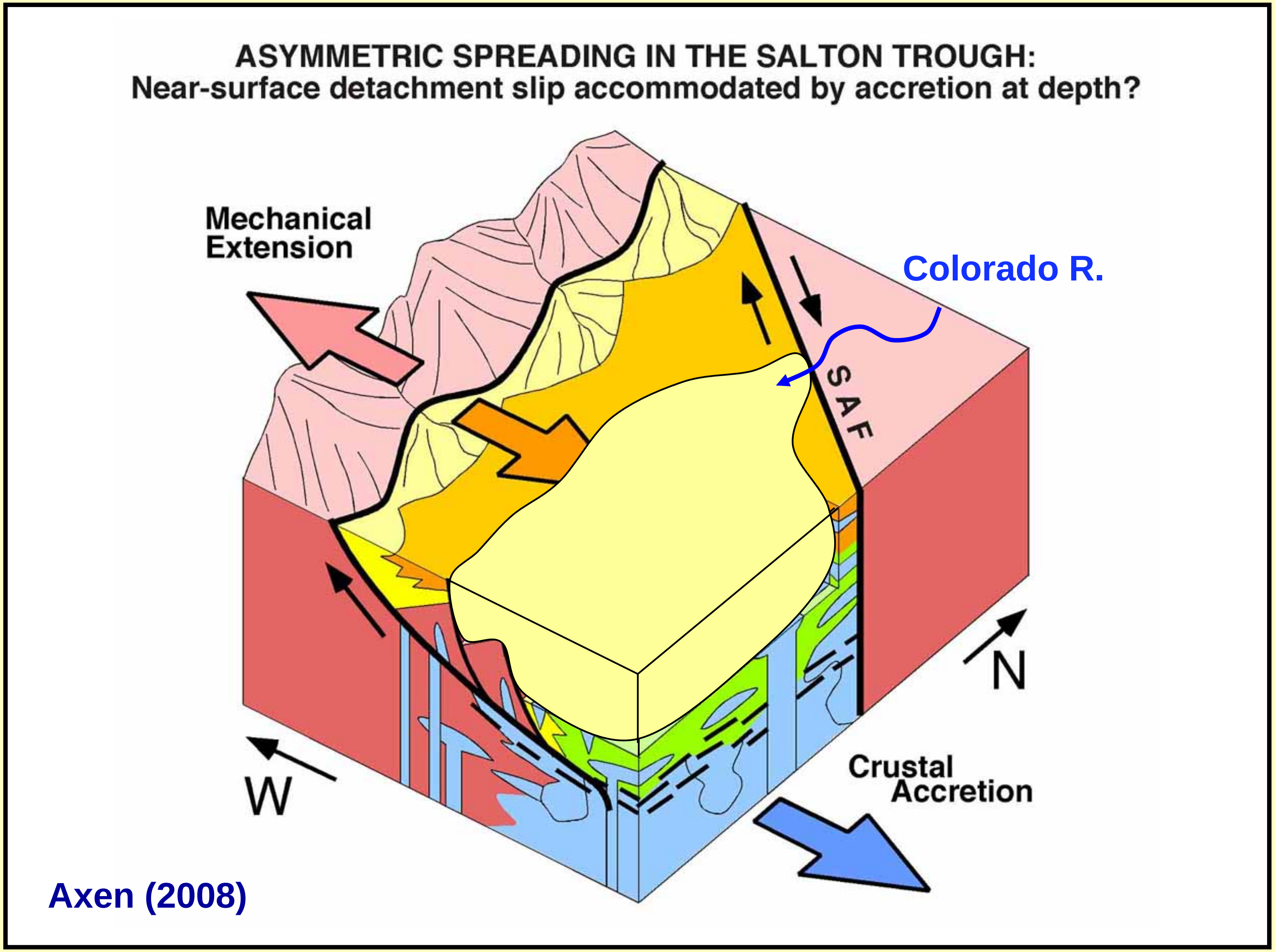
Retro-foreland basin (ALSO FLEXURAL):

- ***Thrust belt does not migrate toward basin*** …
- Subsidence is slow because the only driver is intermittent growth of the retro-wedge.
- No uplift at end, not incorporated into thrust belt.

"Type examples include Taiwan, the European Alps, and the Pyrenees." (Sinclair, 2012)

Predicted Basin Response:	**Pro**-wedge and foreland basin	**Retro**-wedge and foreland basin
Stratal Onlap?	Yes	No
Subsidence Starts	Late: ***after*** onset of orogenesis	Early: ***at*** onset of orogenesis
Subsidence Evolution	Accelerating, Rapid	Decelerating, Slow
Steady-state subsidence?	Yes	No
Uplift at End?	Yes	No

(Compiled from: Sinclair et al., 2005; Naylor and Sinclair, 2007, 2008; Sinclair, 2012; Sinclair and Naylor, 2012)



Linked slip on southern SAF and west Salton detachment fault. Space created by lithospheric rupture is filled with basaltic intrusions from below and voluminous sediment input from above (mainly Colorado River).


Unconformity