Timing & Magnitude of Transform Faulting in the Northern Gulf of CA: Implications for Oblique Rift Localization and Reconstructions of the Pacific-North America Plate Boundary

Graduate Student Research Grant

Richard Chambers Memorial Scholarship

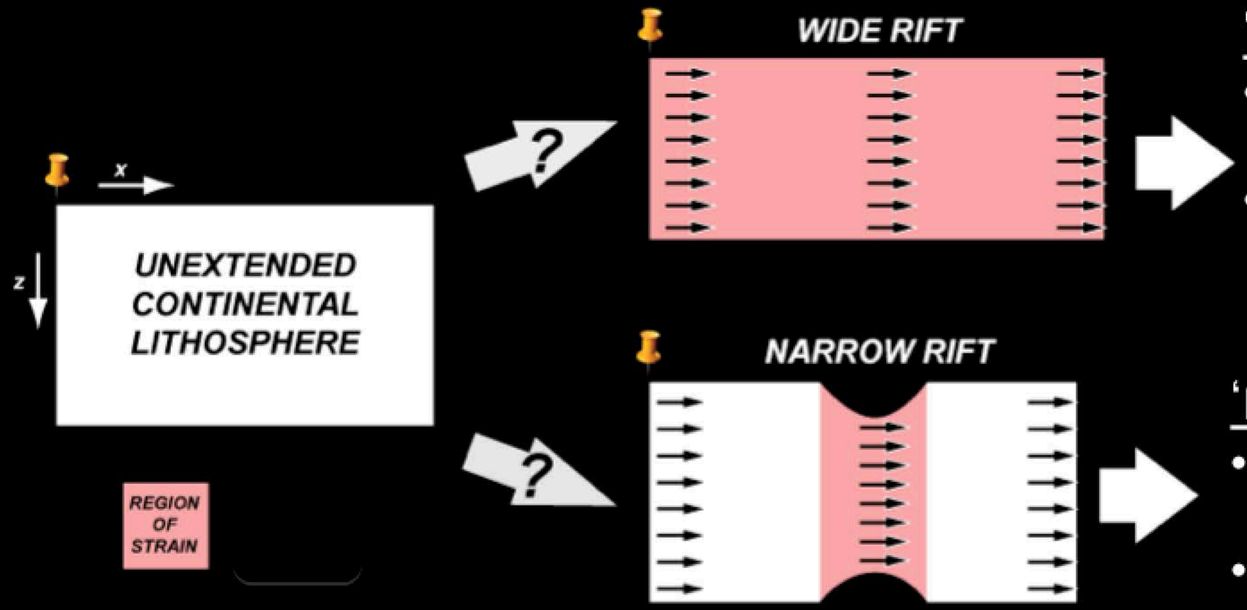
UCD Durrell Funds

Scott Bennett
Mike Oskin
Alex Iriondo

GSA Cordillera Mtg
May 21, 2013

How do Continents Rupture?

Continental rupture requires <u>localization</u> of lithospheric thinning ("necking")



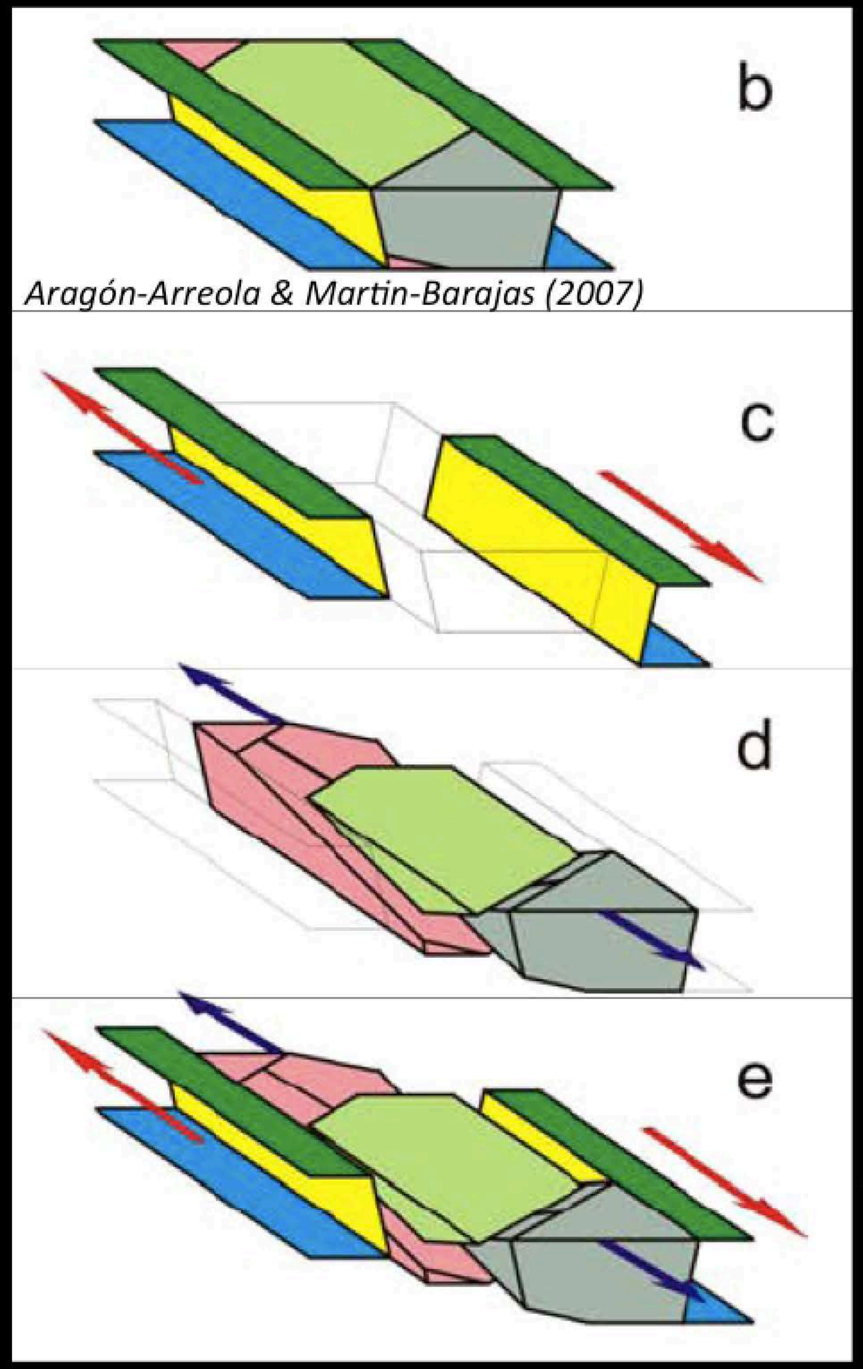
<u>'Wide' rifts:</u>

- diffuse deformation
- diffuse thinning

<u>'Narrow' rifts:</u>

- localized deformation
- localized thinning

How do Oblique Rifts Rupture?



Aragón-Arreola & Martin-Barajas (2007)

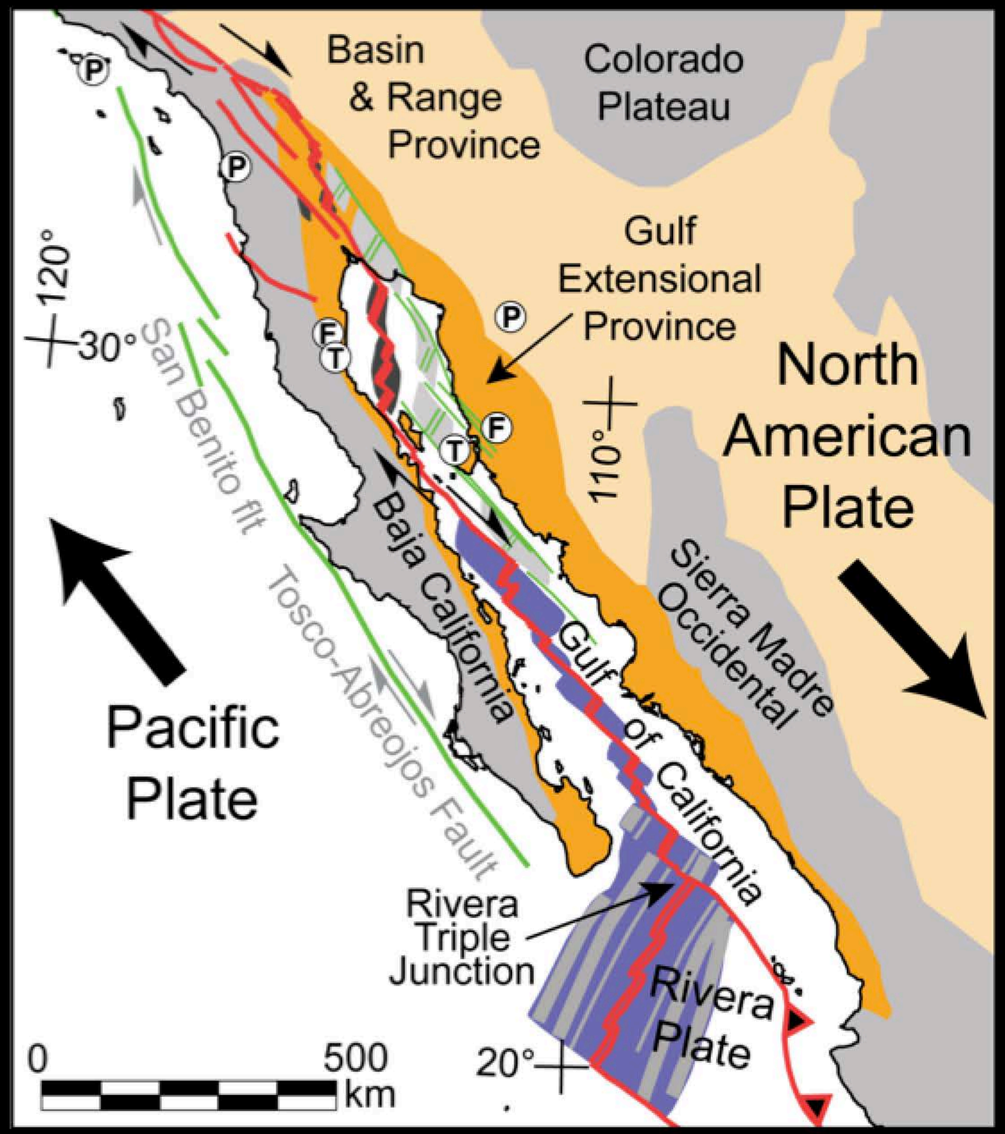
Extensional regions hosting strike-slip faults may have higher potential for:

- focused strain
- rapid crustal thinning
- large-offset normal faults

Oblique rifts can be very efficient at thinning the lithosphere.

Kinematically-Linked Transtensional Structures

Gulf of California



Oskin & Stock (2003), Arregón-Arreola & Martín-Barajas (2007), Fletcher et al. (2007)

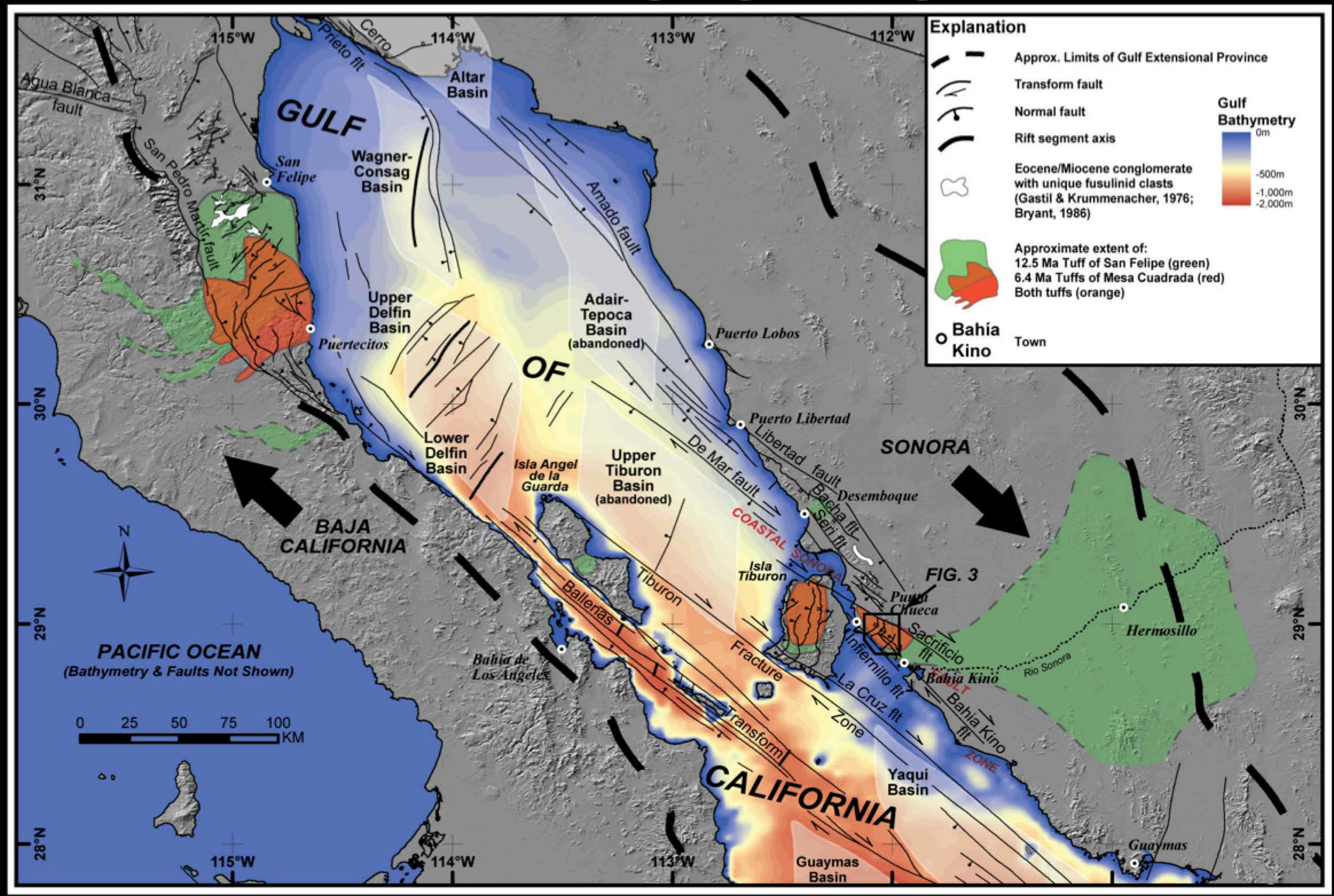
Ideal to Study Oblique Rifts

- recent strain localization - ca. 6 Ma
- GOC is highly oblique continental rift
  - <30° angle
- multiple cross-Gulf tie points
  - (P) Poway conglomerate (Eocene)
  - (F) distinctive fusulinid-rich clast conglomerate (Eocene/Miocene?)
  - (T) tuff sequence (Miocene)

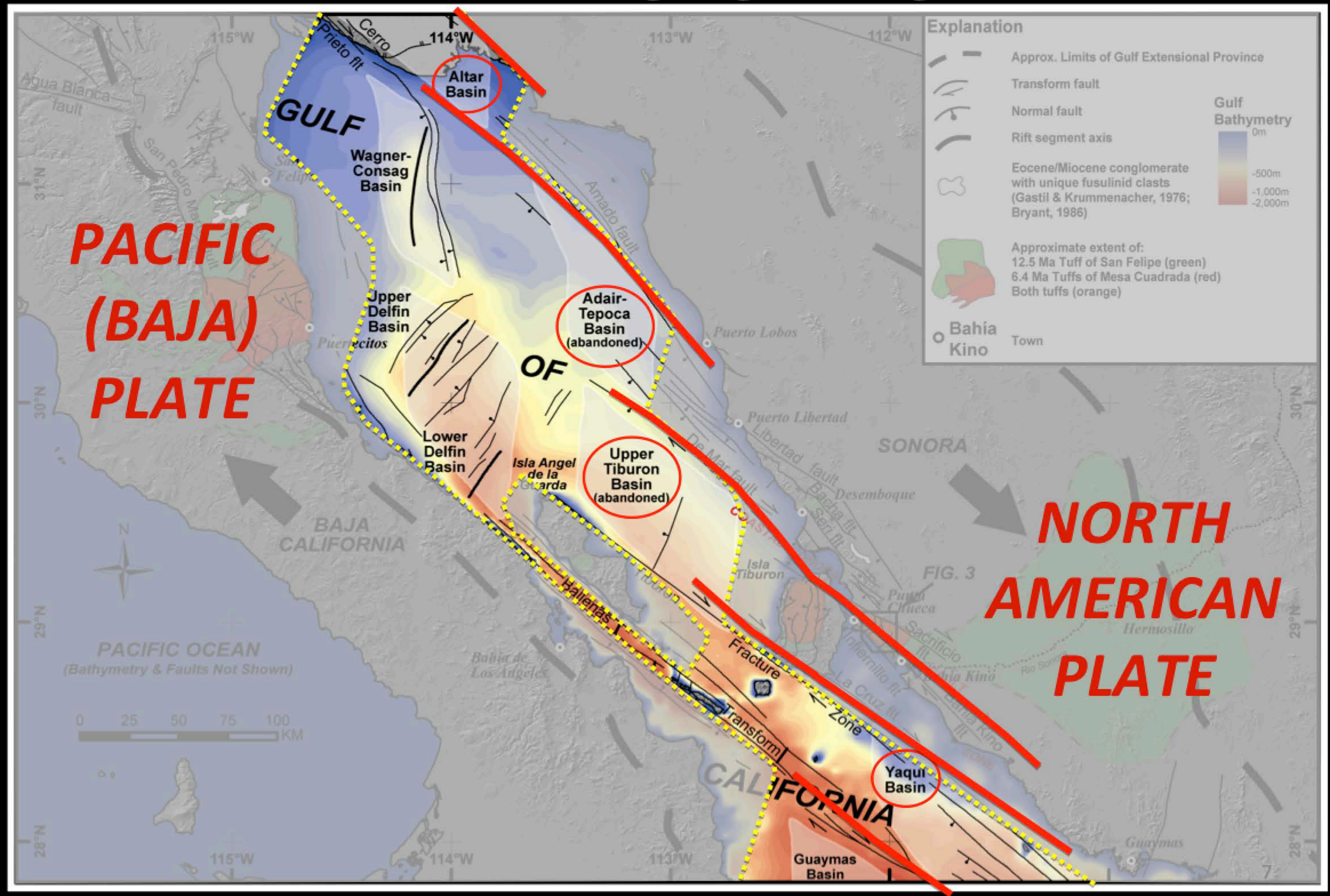
HYPOTHESIS

Strike-slip faults played a role in localizing plate boundary strain.

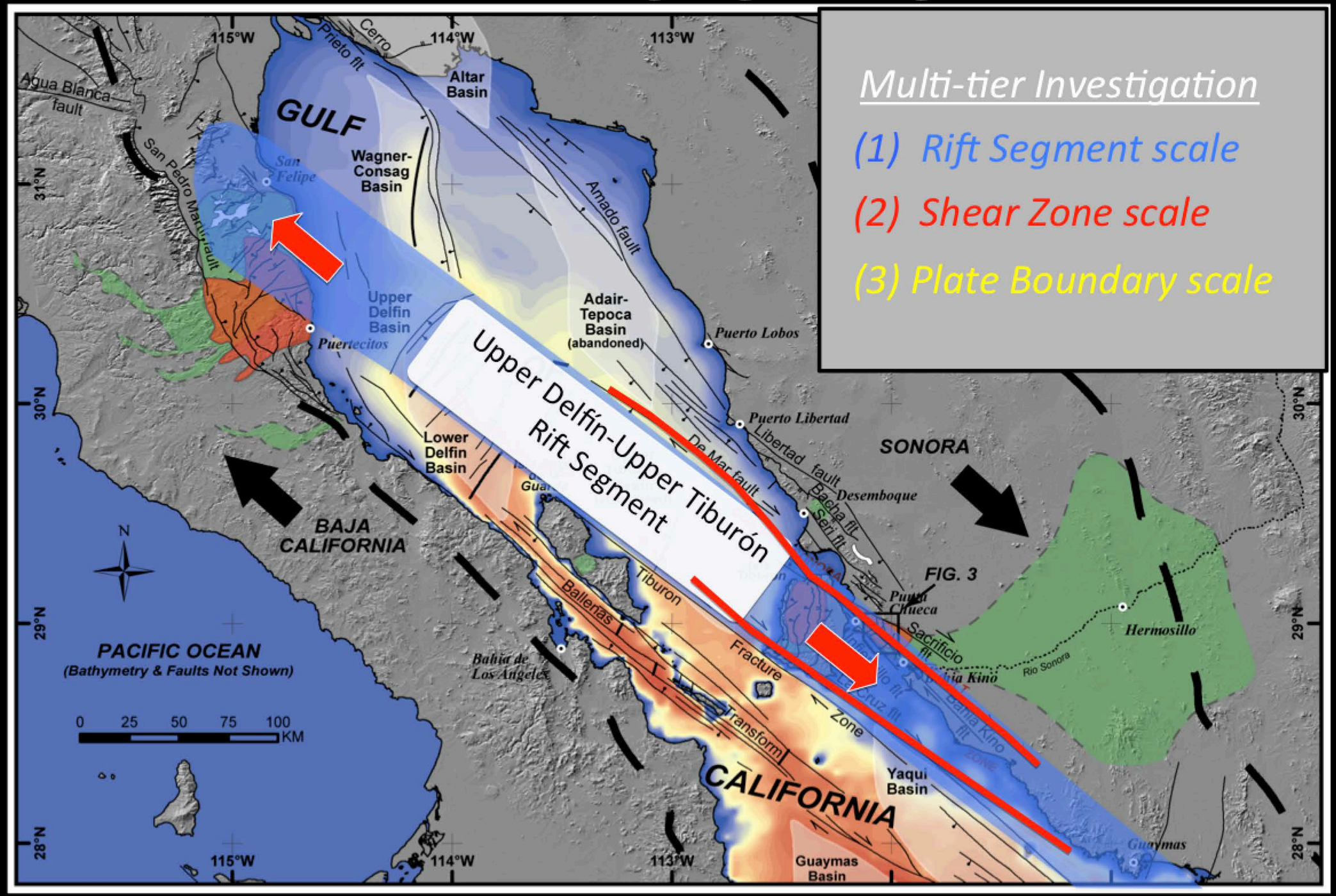
Northern Gulf of California



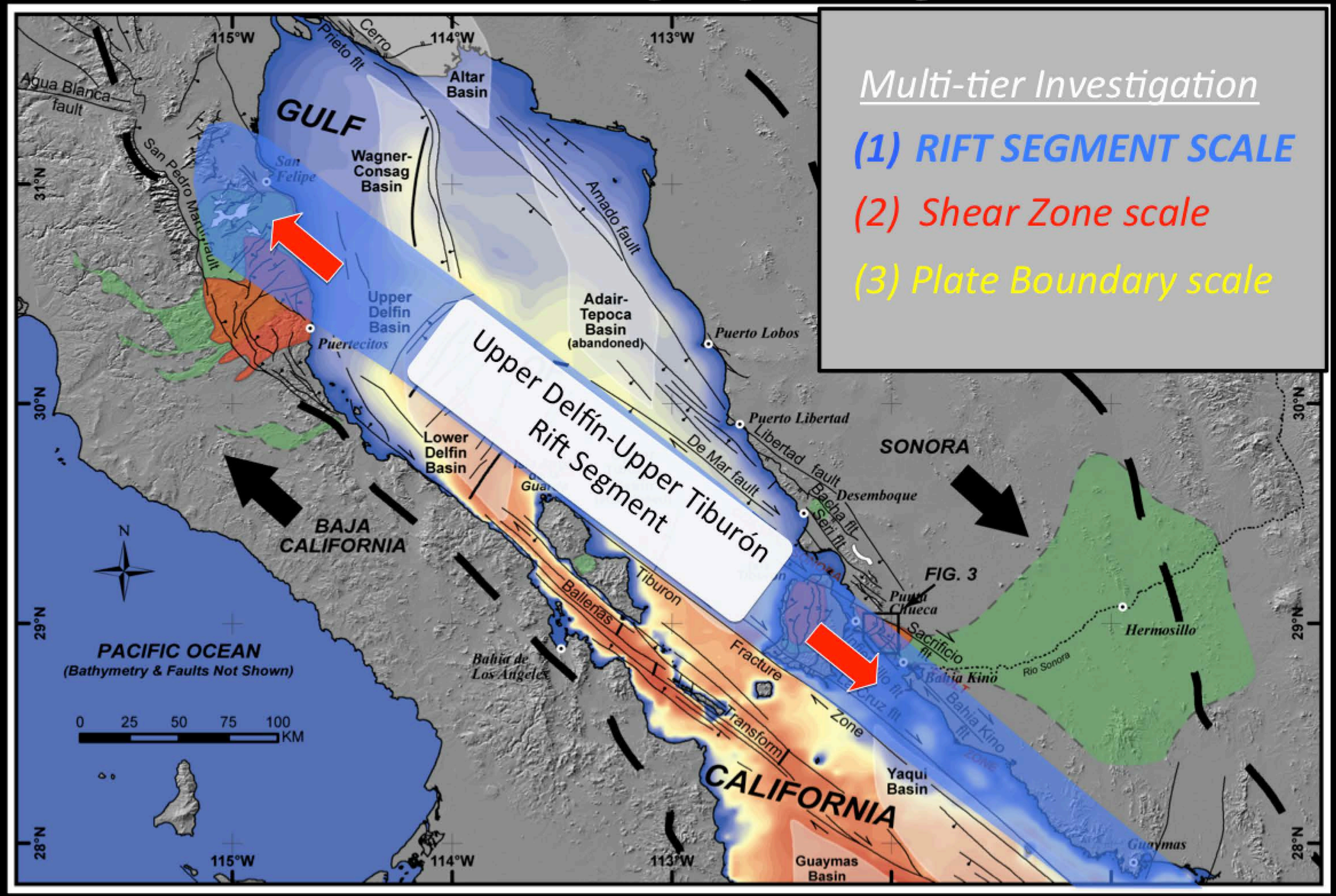
Northern Gulf of California



Northern Gulf of California



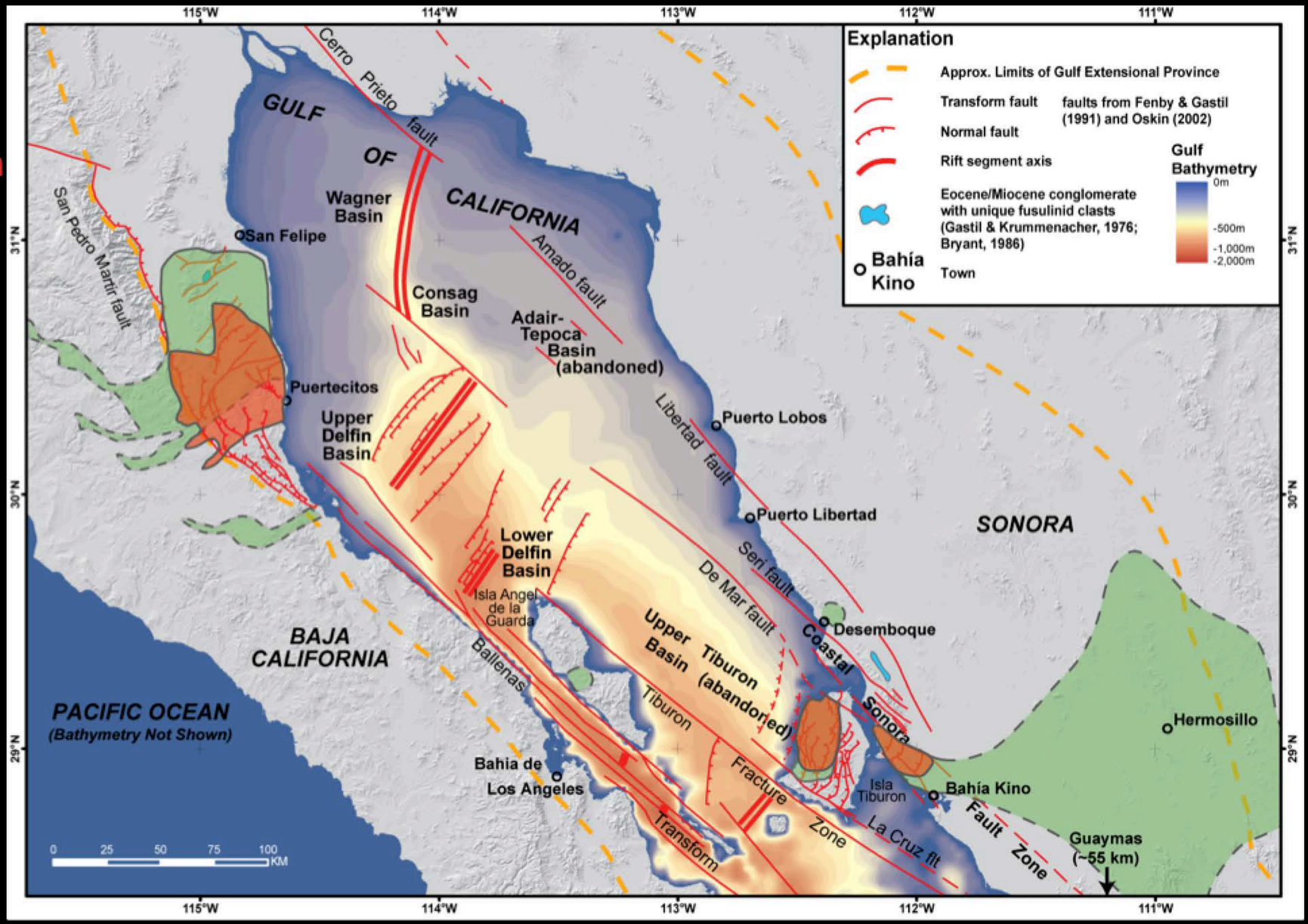
Northern Gulf of California



Rift Segment Paleomagnetic Study

6.4 Ma
Tuffs of Mesa Cuadrada

12.5 Ma
Tuff of San Felipe



Bennett & Oskin (In Review)

Rift Segment Paleomagnetic Study

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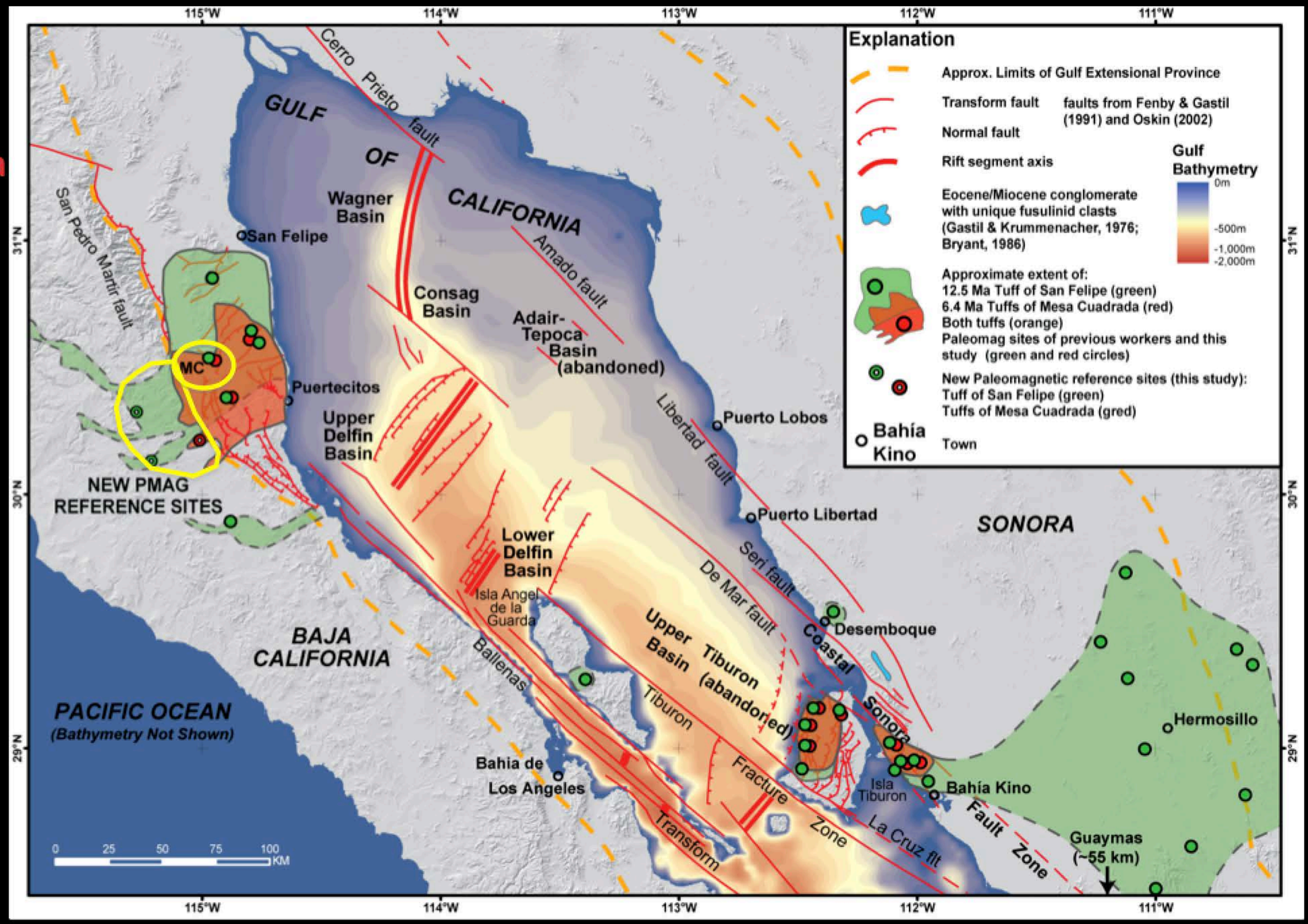

Bennett & Oskin (In Review)

Rift Segment Paleomagnetic Study

6.4 Ma
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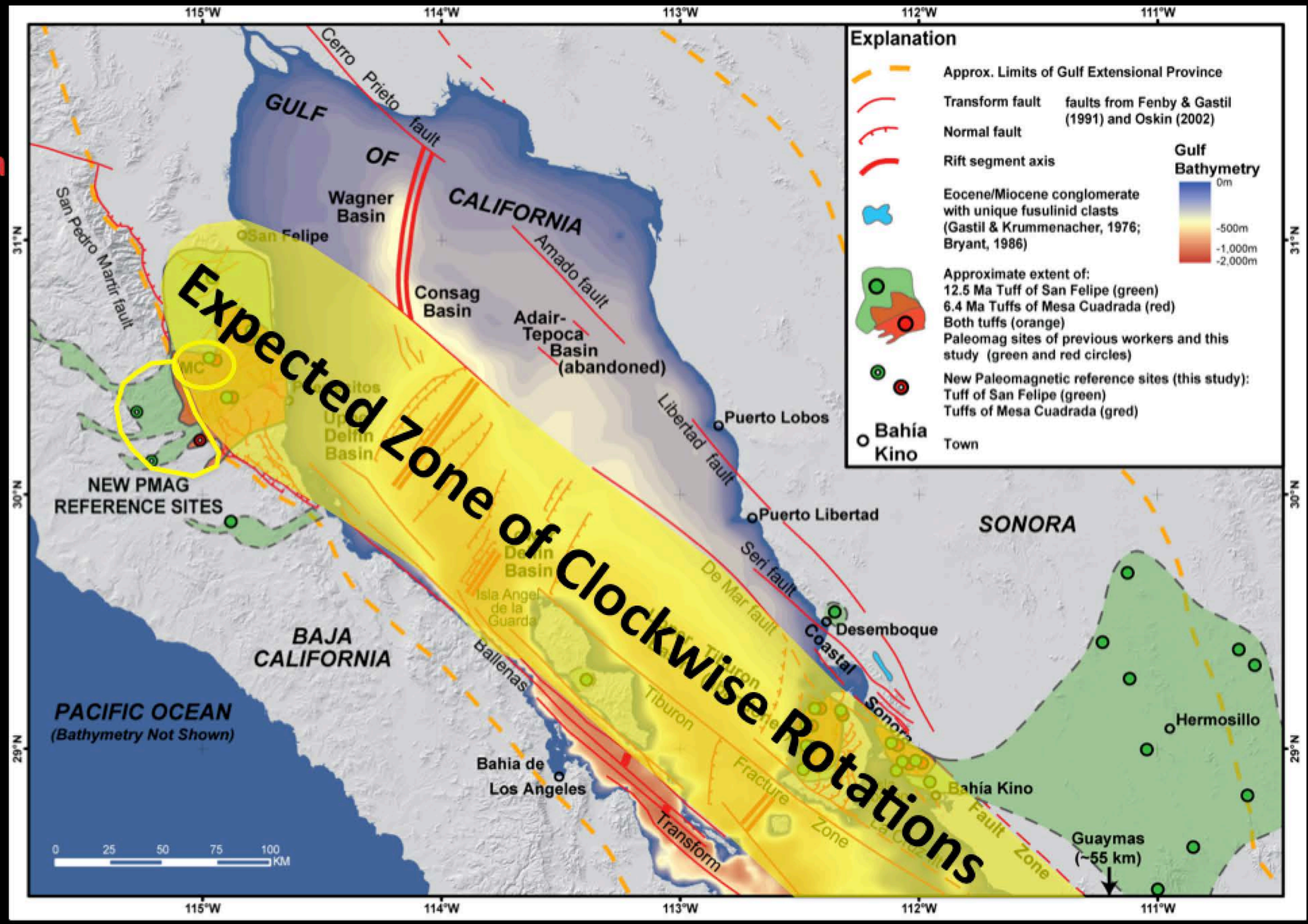
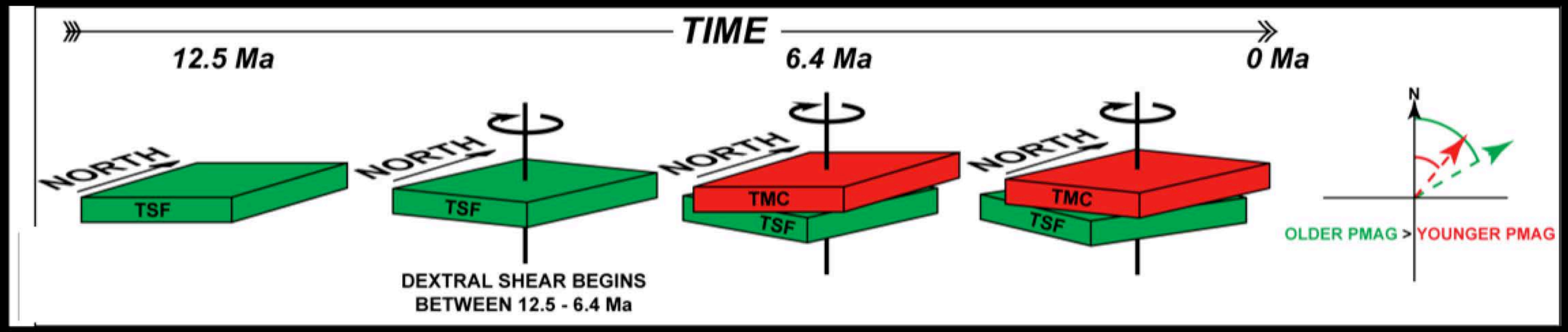


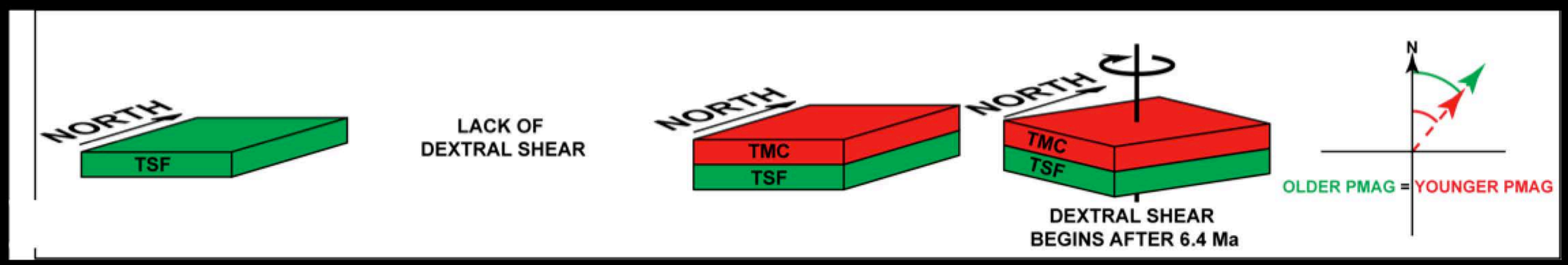
Bennett & Oskin (In Review)

Rift Segment Paleomagnetic Study

Paired paleomagnetic sites can provide timing information.

Proto-Gulf Dextral Shear





LACK OF Proto-Gulf Dextral Shear

Rift Segment Paleomagnetic Study

6.4 Ma Tuffs of Mesa Cuadrada, central Baja California

New Reference Sites in central Baja (TSF)

drill site example (TMC)

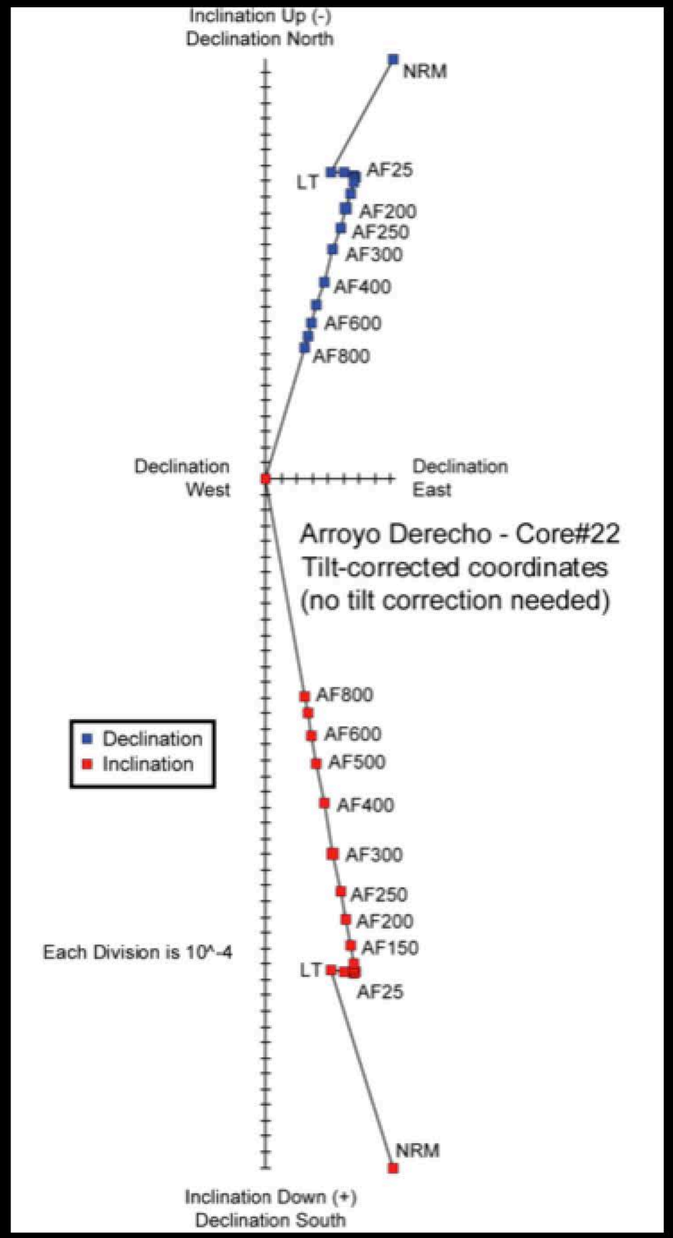
Rift Segment Paleomagnetic Study

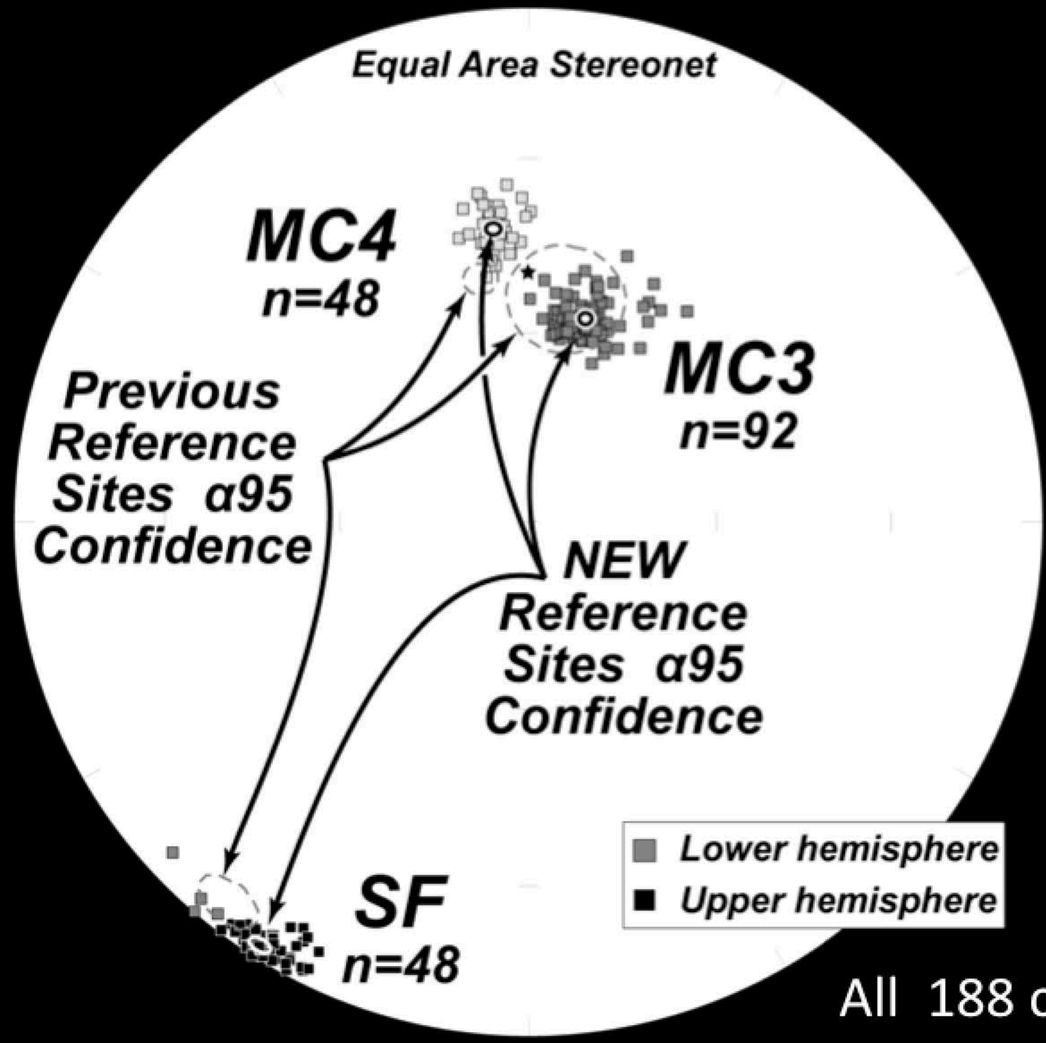
a Cuadrada, central Baja California

New Reference Sites in central Baja (TSF)

drill site example (TMC)

Rift Segment Paleomagnetic Study

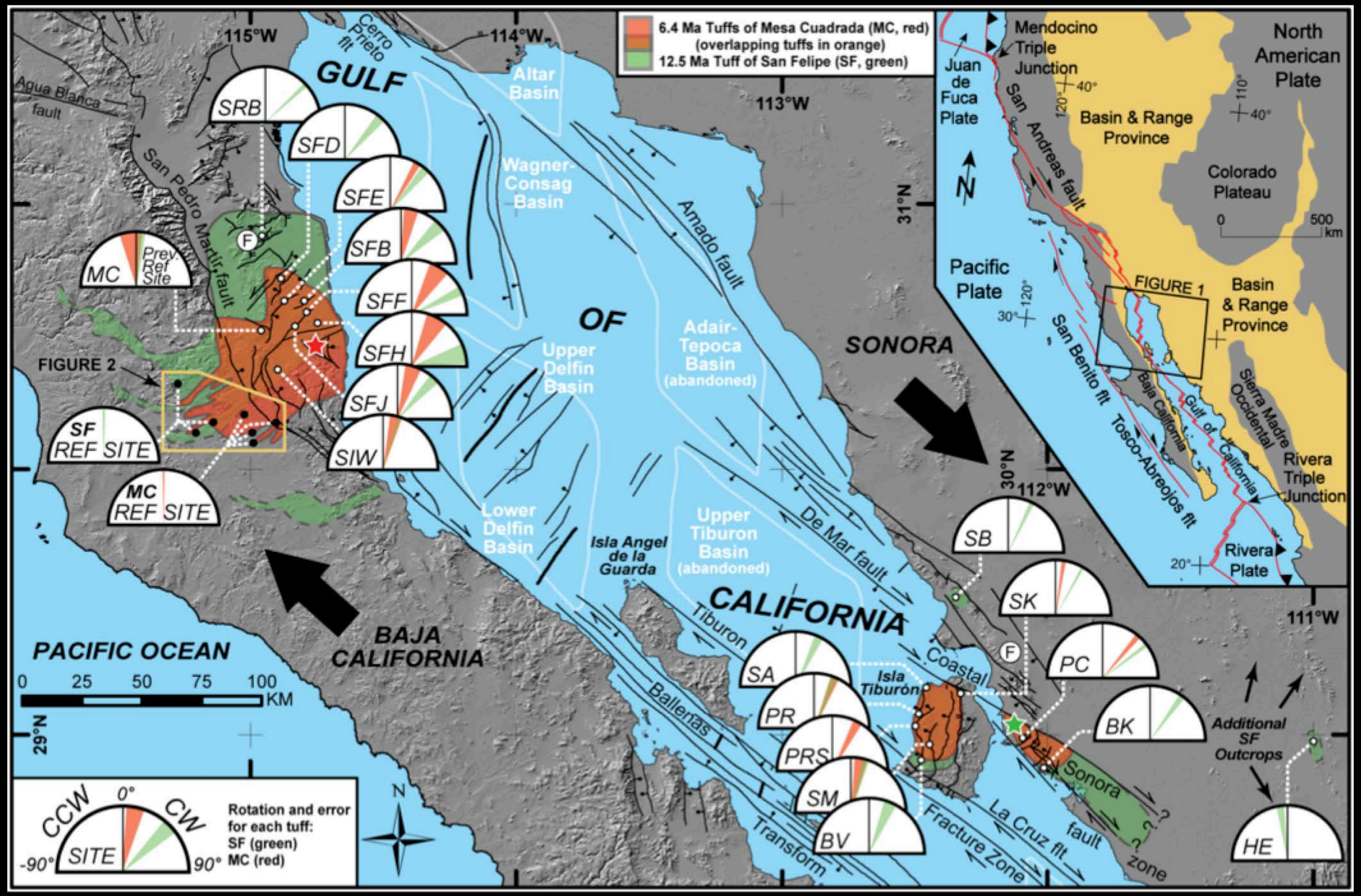




All 188 cores

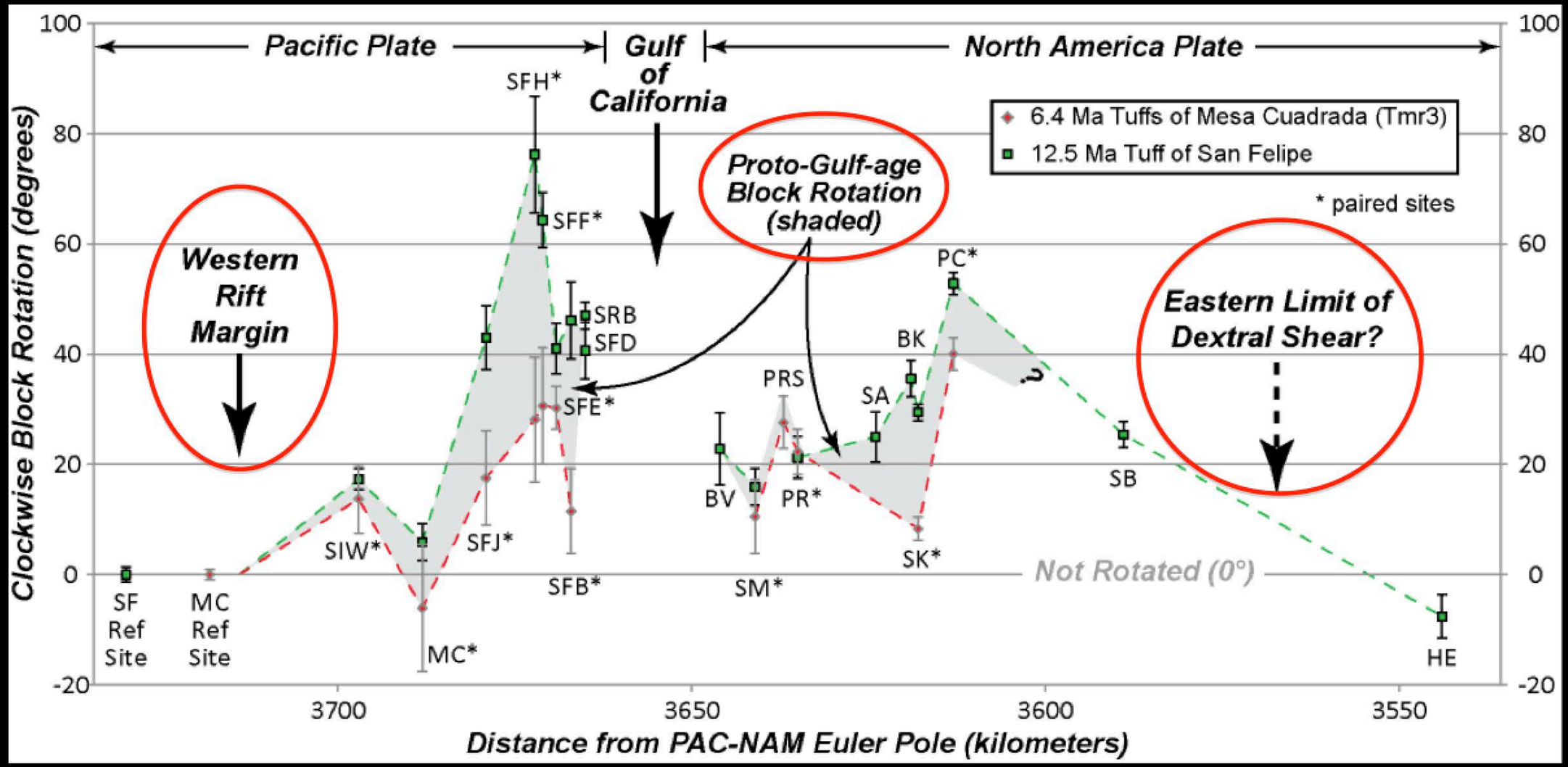
6.4 Ma Tuffs of Mesa Cuadrada,
central Baja California

Spatial Patterns of Block Rotation



Bennett & Oskin (In Review)

Spatial Patterns of Block Rotation



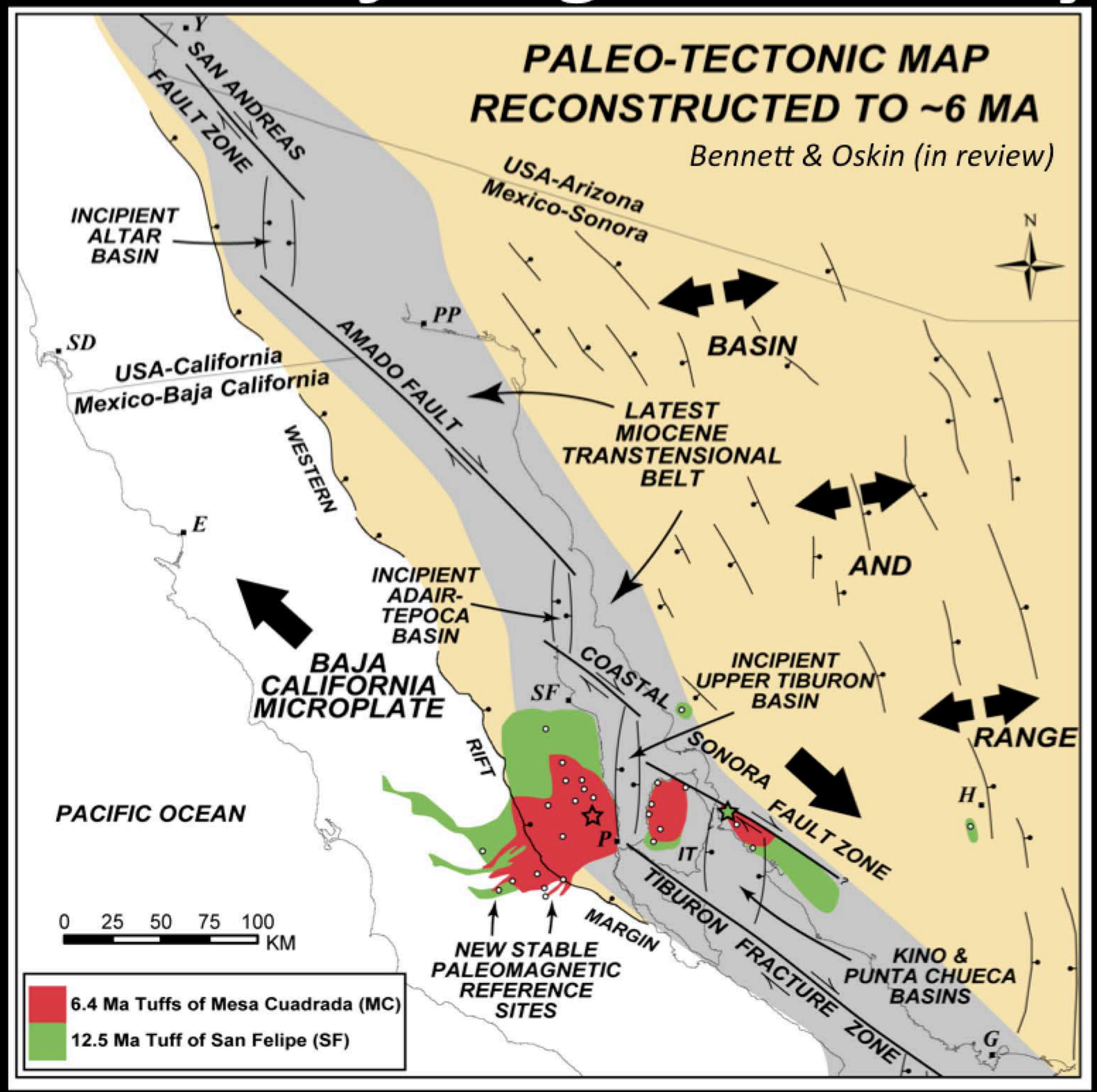
Bennett & Oskin (In Review)

CONCLUSIONS - Rift Segment Study

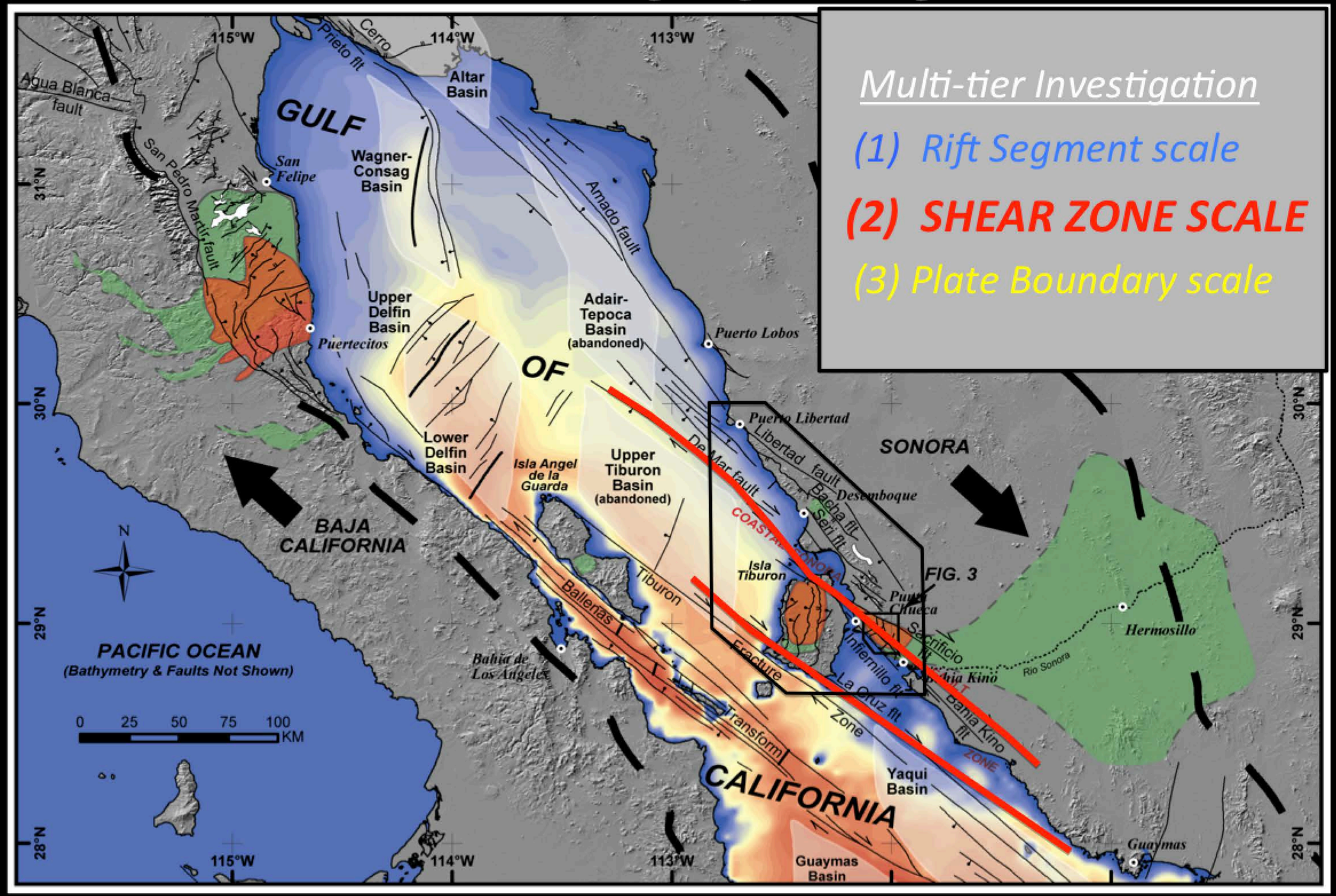
DISTRIBUTION:
~50-100 km wide transtensional belt

MAGNITUDE:
~20-70° of CW block rotation

TIMING:
~48% of CW rotation occurred pre-6.4 Ma



Northern Gulf of California



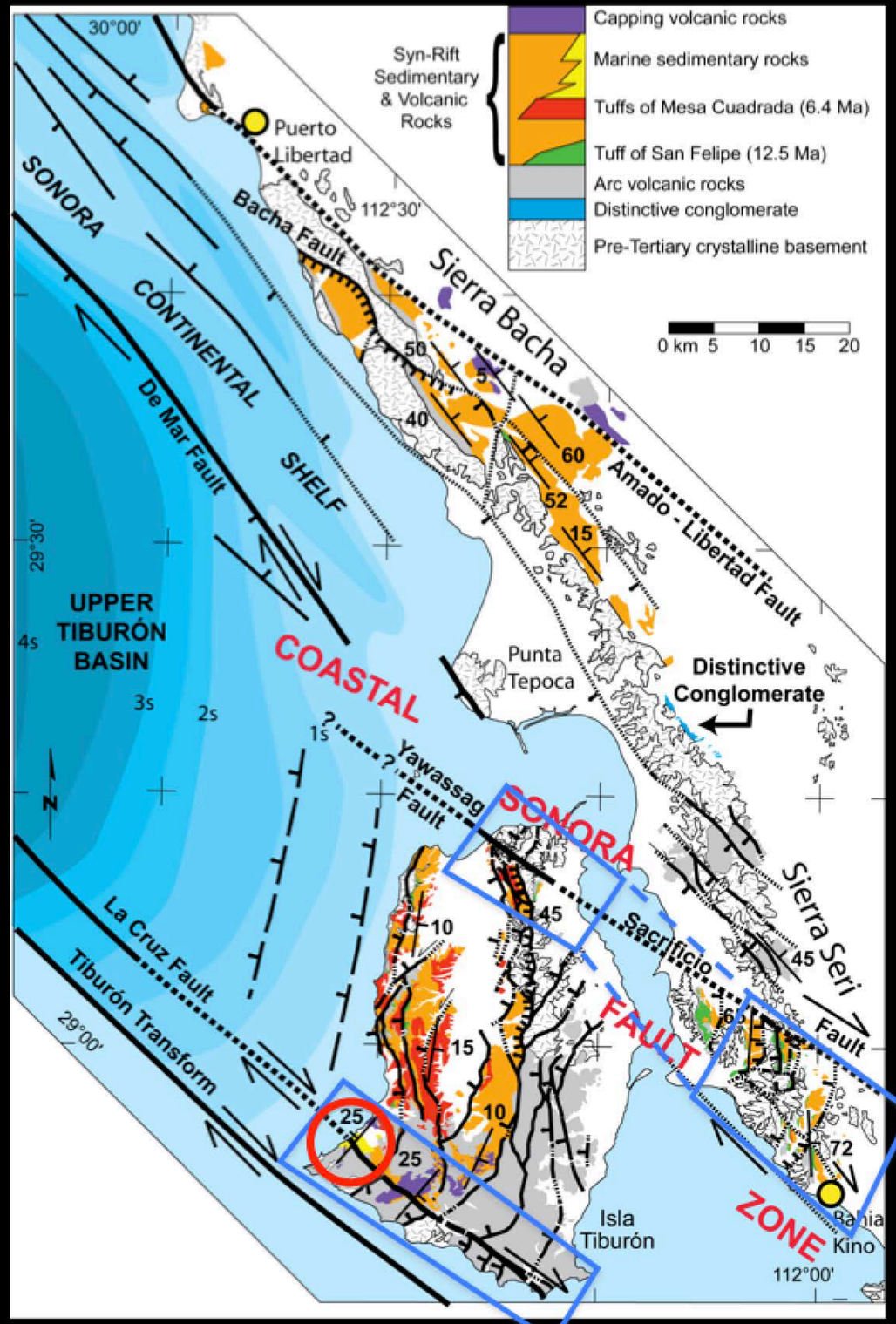
Multi-tier Investigation

(1) Rift Segment scale

(2) SHEAR ZONE SCALE

(3) Plate Boundary scale

Regional Geology



Shear zones

- Coastal Sonora Fault Zone
- La Cruz fault & Tiburon Transform fault

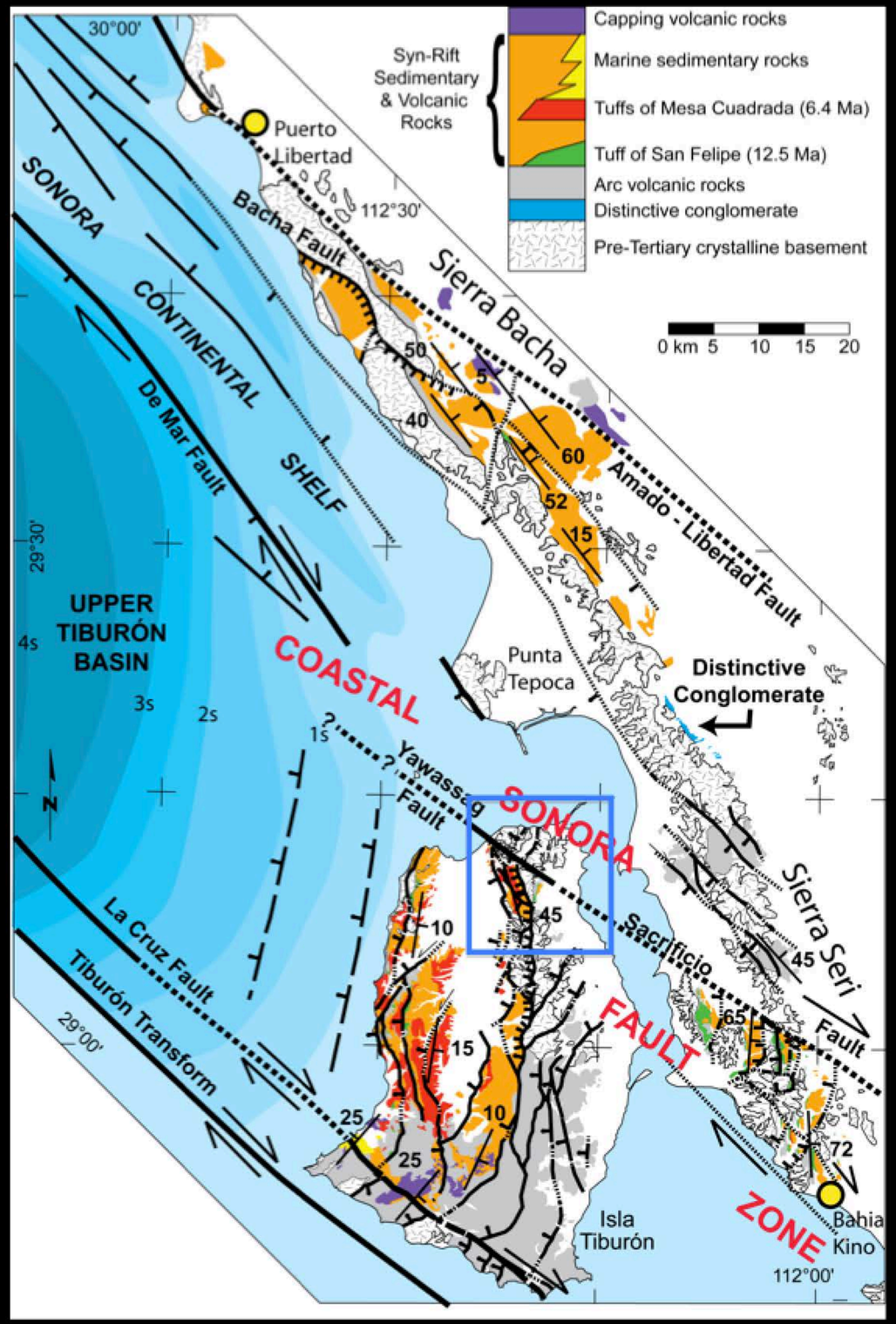
METHODS

1:10,000-scale Mapping

Stratigraphy of sedimentary basins

Geochronology of volcanic rocks

Structural analysis



NE Isla Tiburon

Coastal Sonora Fault Zone

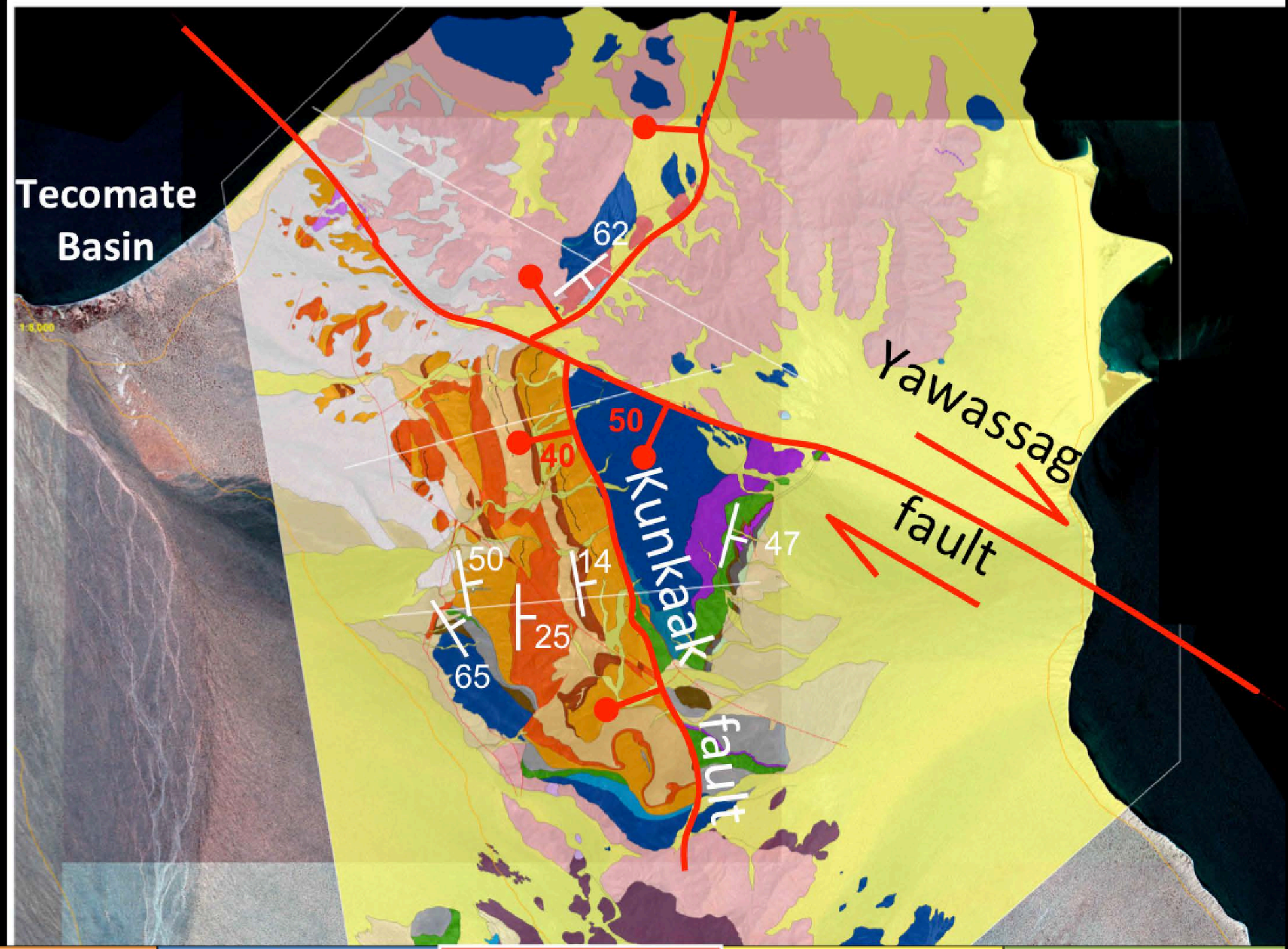
- strike-slip faults
- normal faults

Syn-rift non-marine sedimentary basins

- Tecomate basin

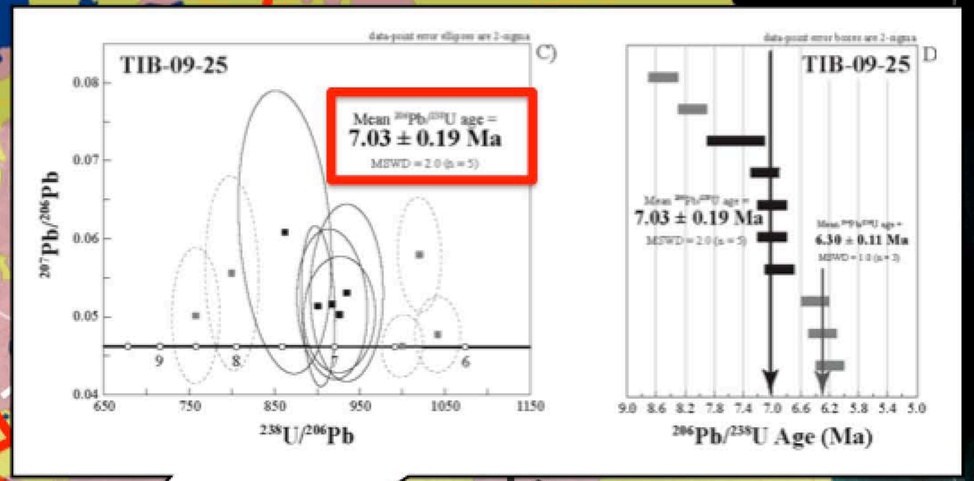
NE Isla Tiburon: Mapping & Geochronology

NE Isla Tiburon: Mapping & Geochronology

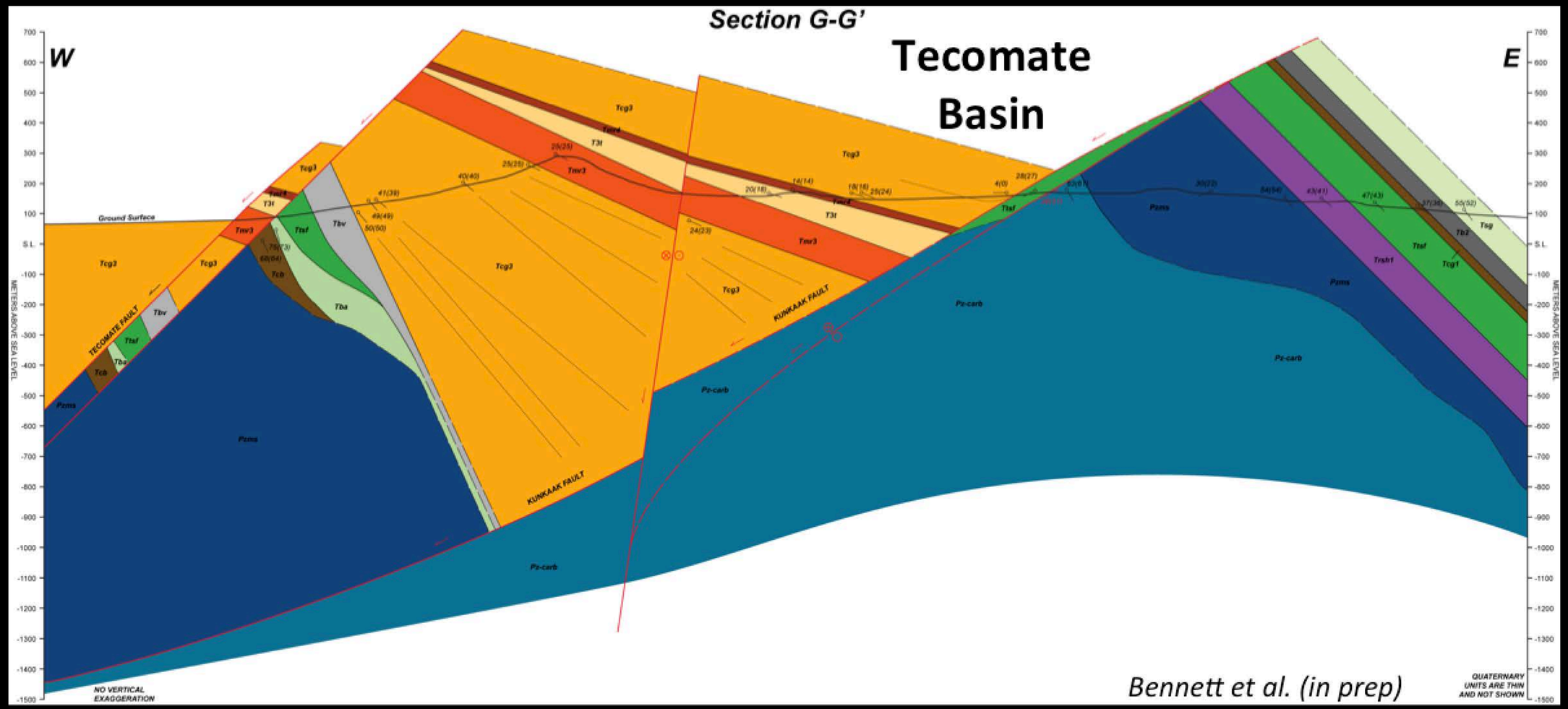


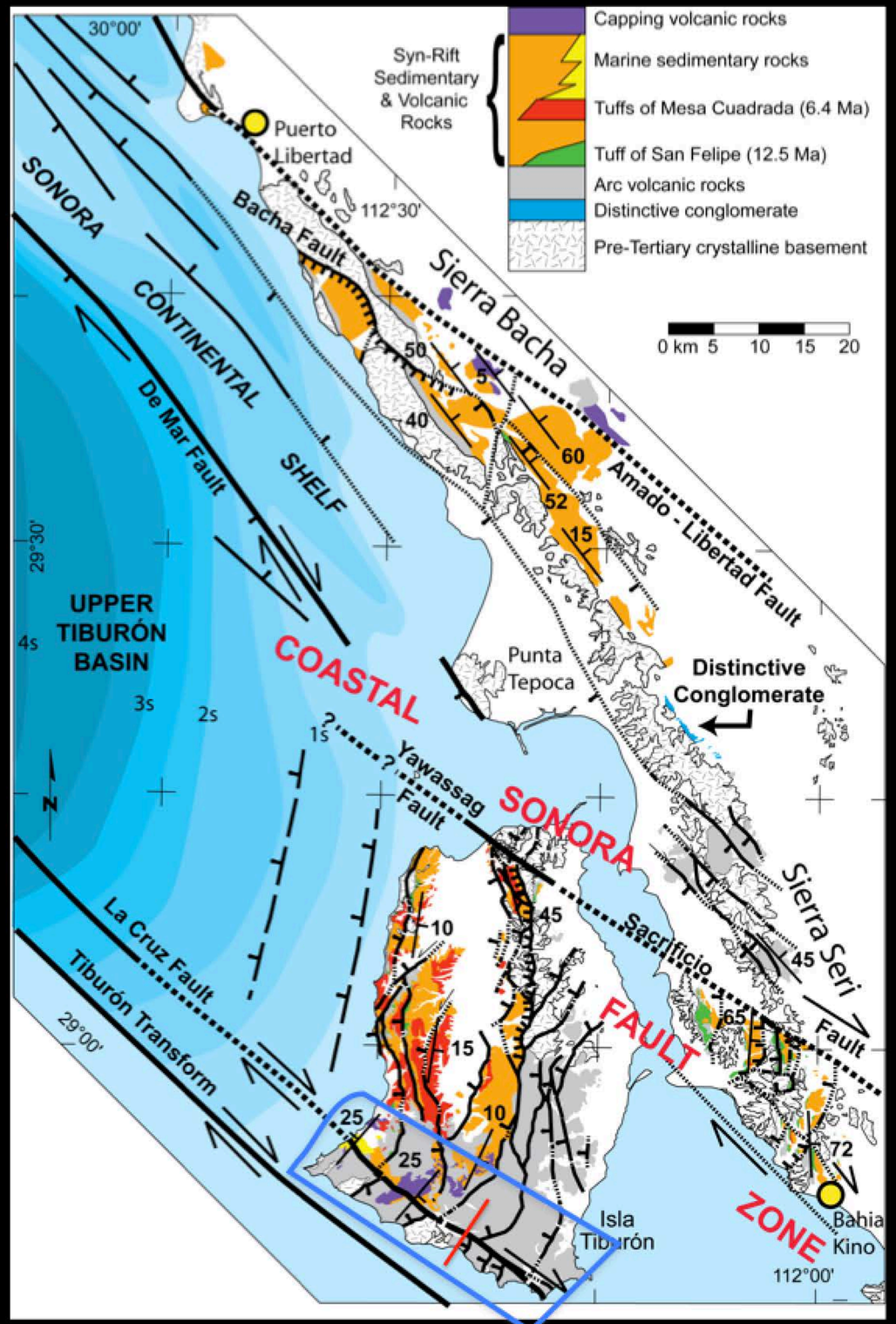
NE Isla Tiburon: Mapping & Geochronology

Transtensional Basin Formation & >8 KM of dextral shear initiated ca. 7 Ma



NE Isla Tiburon: Mapping & Geochronology





Southern Isla Tiburon

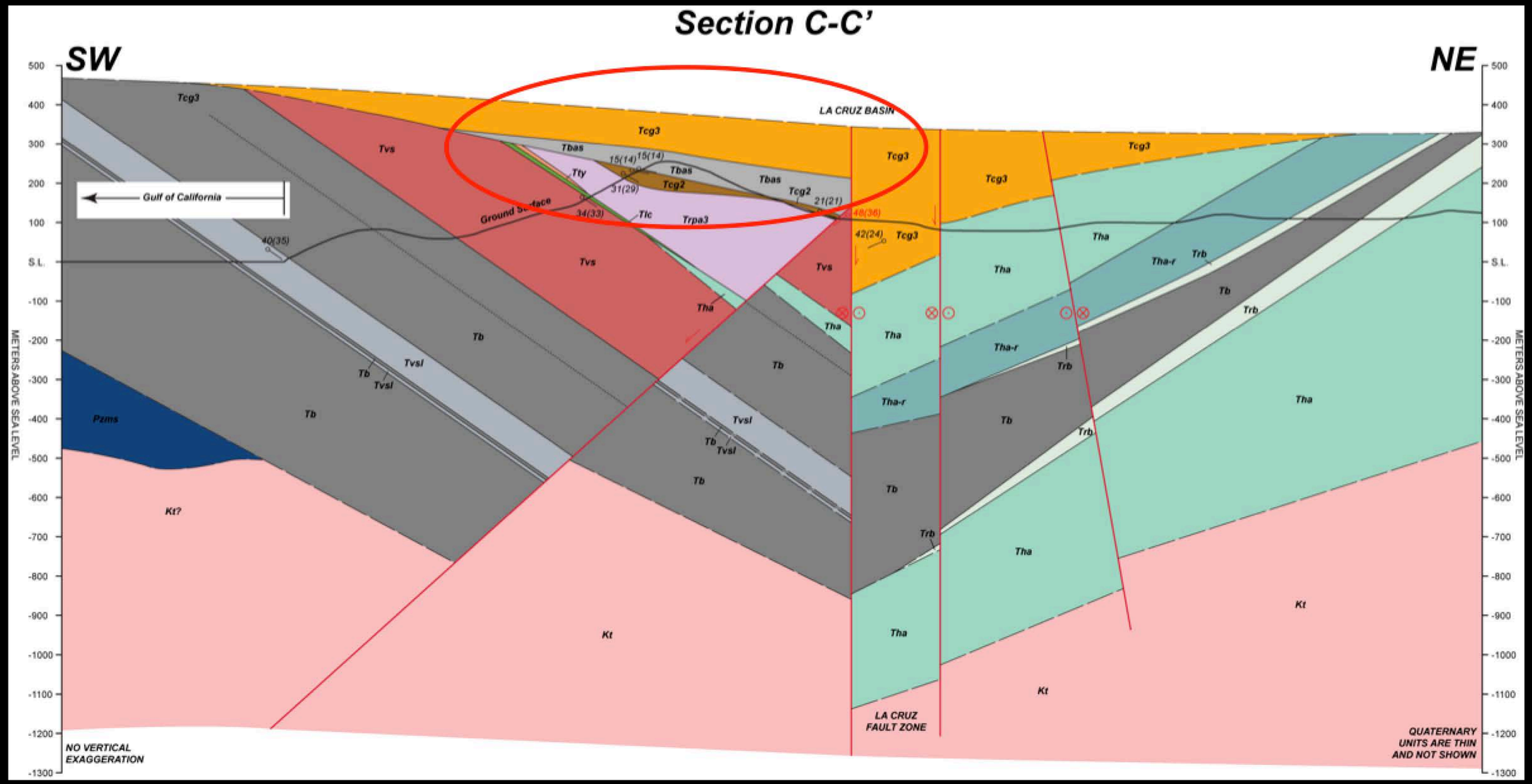
La Cruz fault zone

- La Cruz fault (SS)
- normal faults
- folds and thrust faults

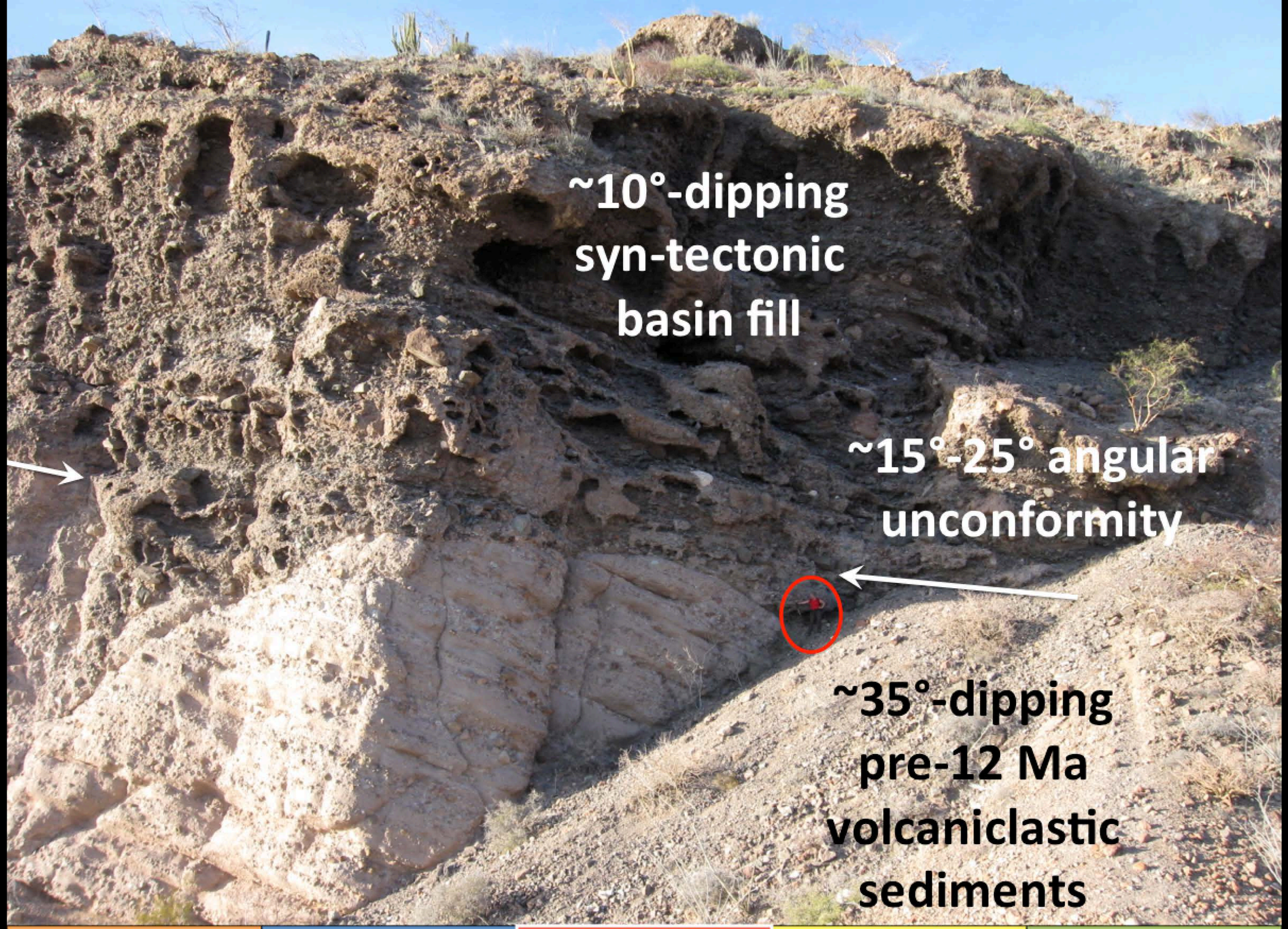
Syn-rift sedimentary basins

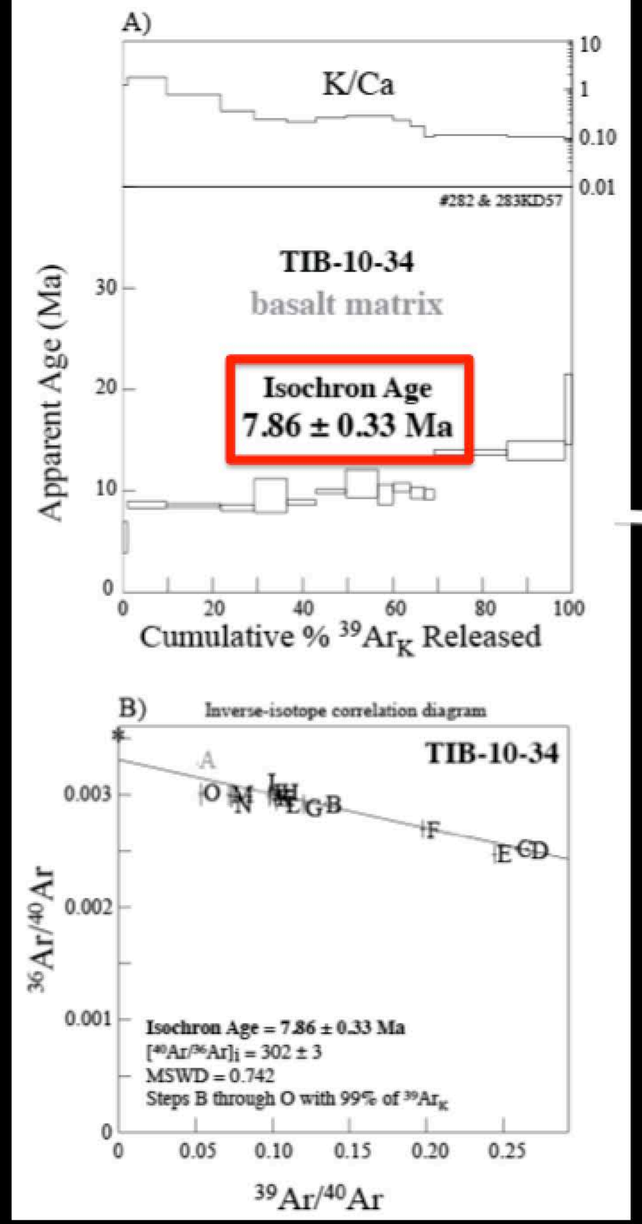
- La Cruz basin (non-marine)
- SW Isla Tiburon basin (marine)

South Isla Tiburon: Mapping & Geochronology



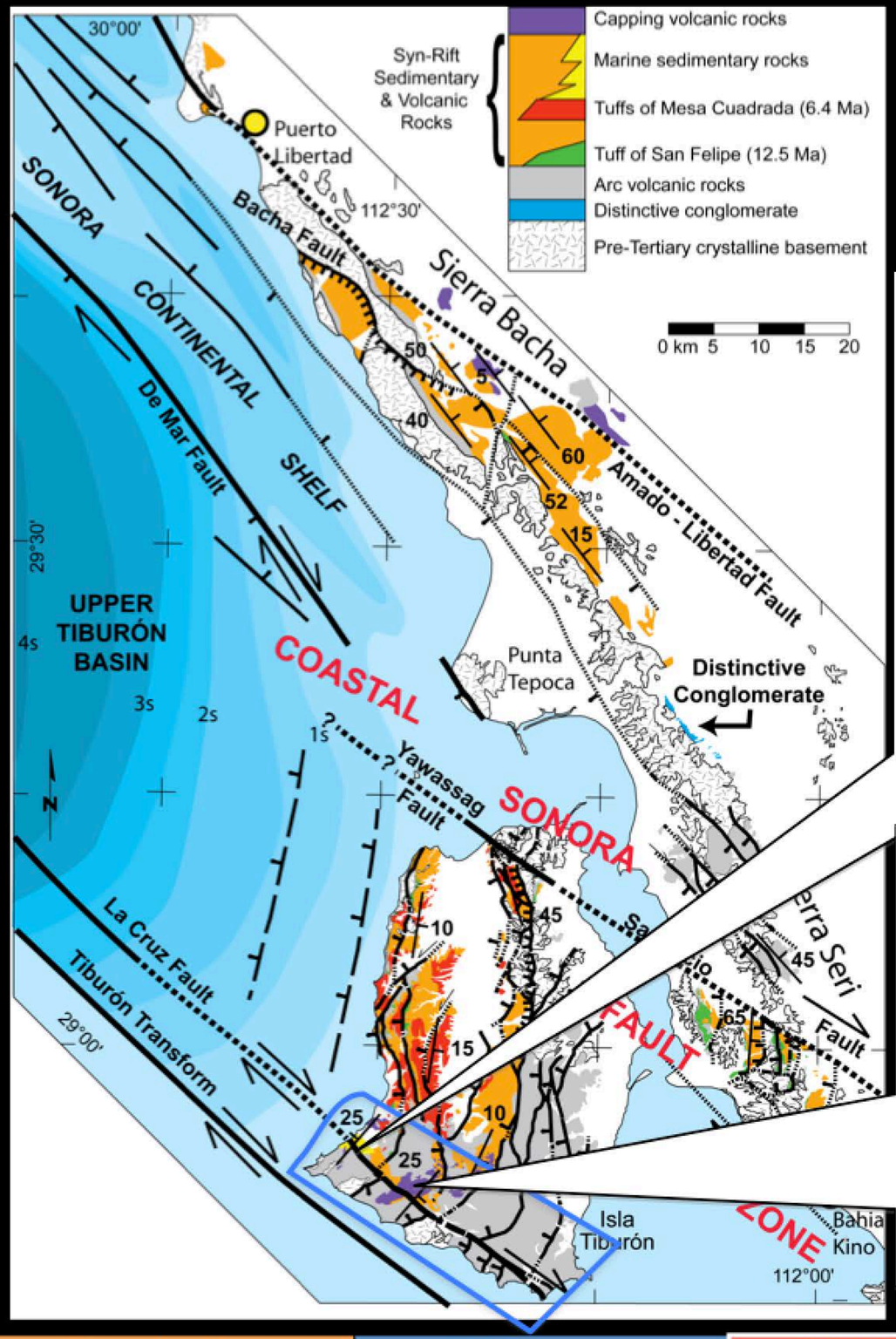
Bennett et al. (in prep)

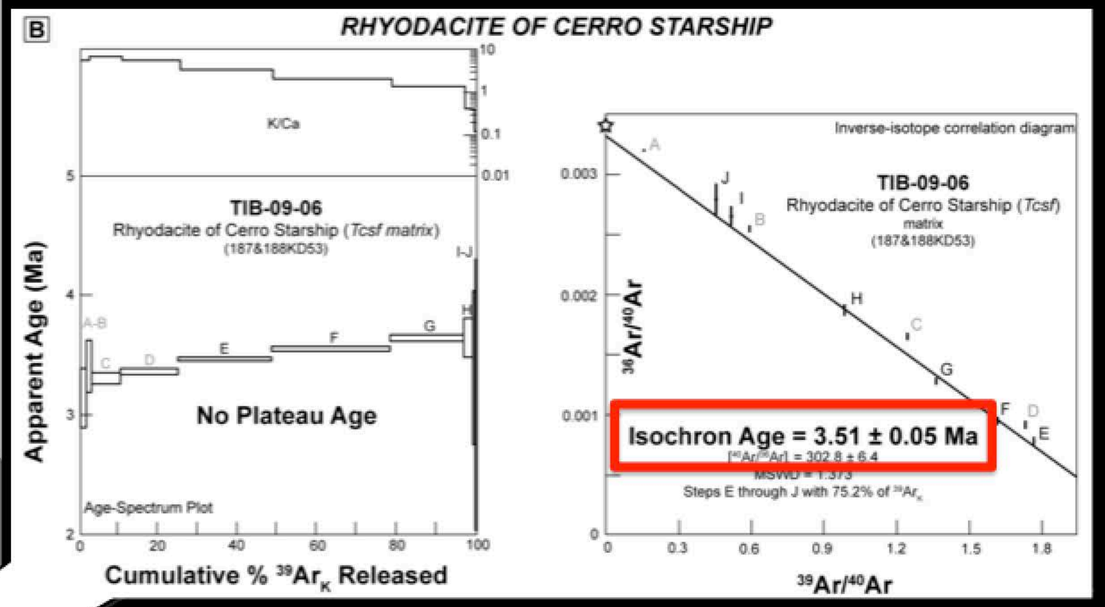

~10°-dipping
syn-tectonic
basin fill
~15°-25° angular
unconformity
~35°-dipping
pre-12 Ma
volcaniclastic
sediments

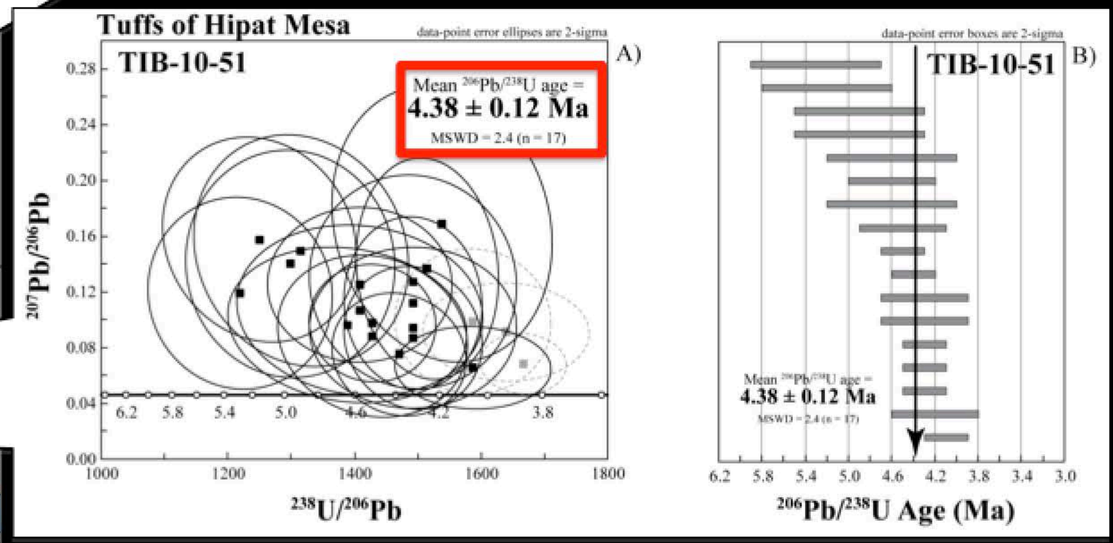

A)
K/Ca
10
1
0.10
0.01
#282 & 283KD57
TIB-10-34
basalt matrix
Isochron Age
7.86 ± 0.33 Ma
Apparent Age (Ma)
30
20
10
0
0
20
40
60
80
100
Cumulative % $^{39}Ar_K$ Released
B)
Inverse-isotope correlation diagram
TIB-10-34
0.003
0.002
0.001
0
$^{36}Ar/^{40}Ar$
A
O
M
N
L
H
G
B
F
E
CD
Isochron Age = 7.86 ± 0.33 Ma
$[^{40}Ar/^{36}Ar]_i$ = 302 ± 3
MSWD = 0.742
Steps B through O with 99% of $^{39}Ar_K$
0
0.05
0.10
0.15
0.20
0.25
$^{39}Ar/^{40}Ar$

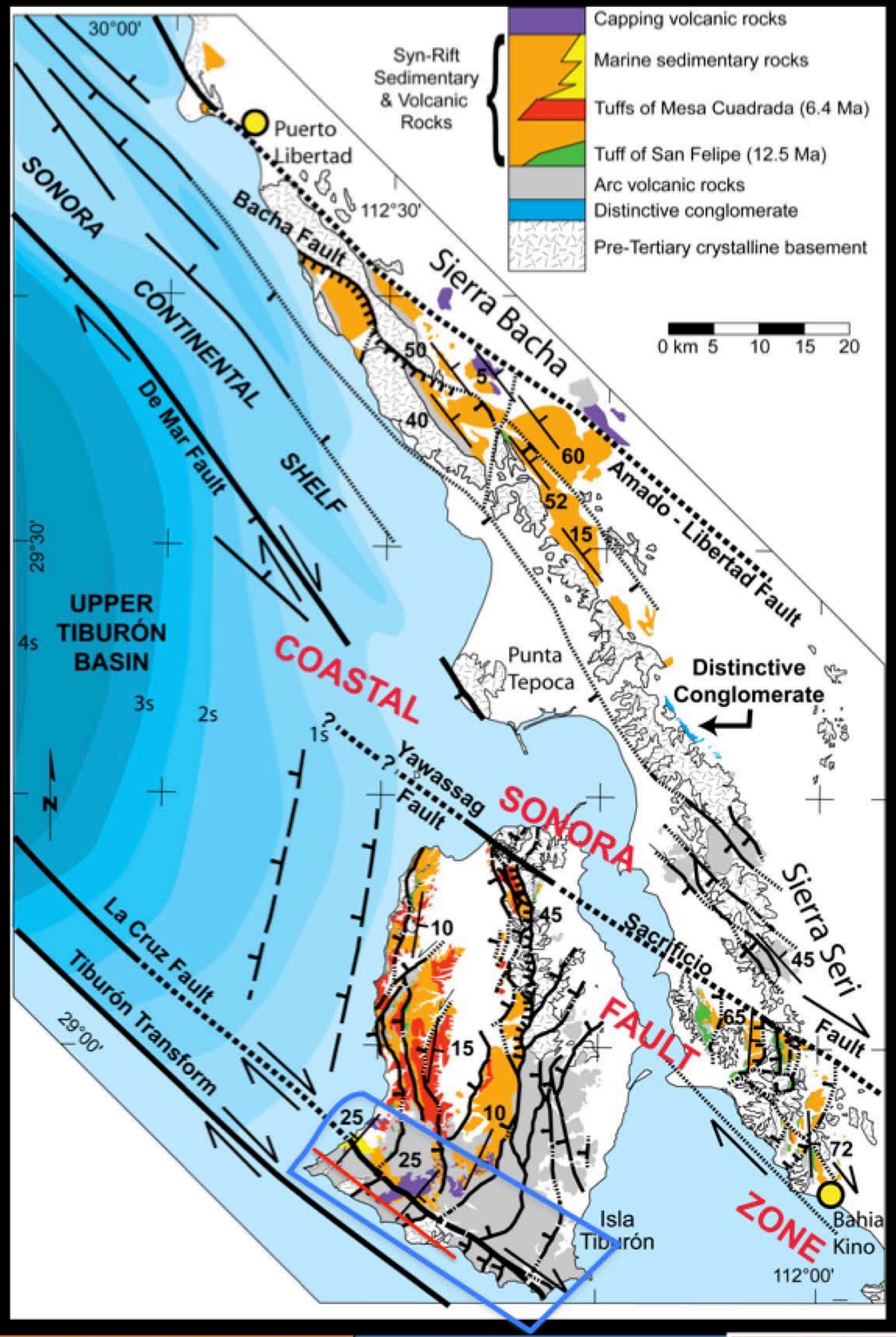

intercalated
basalt breccia
earliest
syn-tectonic
basin
conglomerate

Southern Isla Tiburon







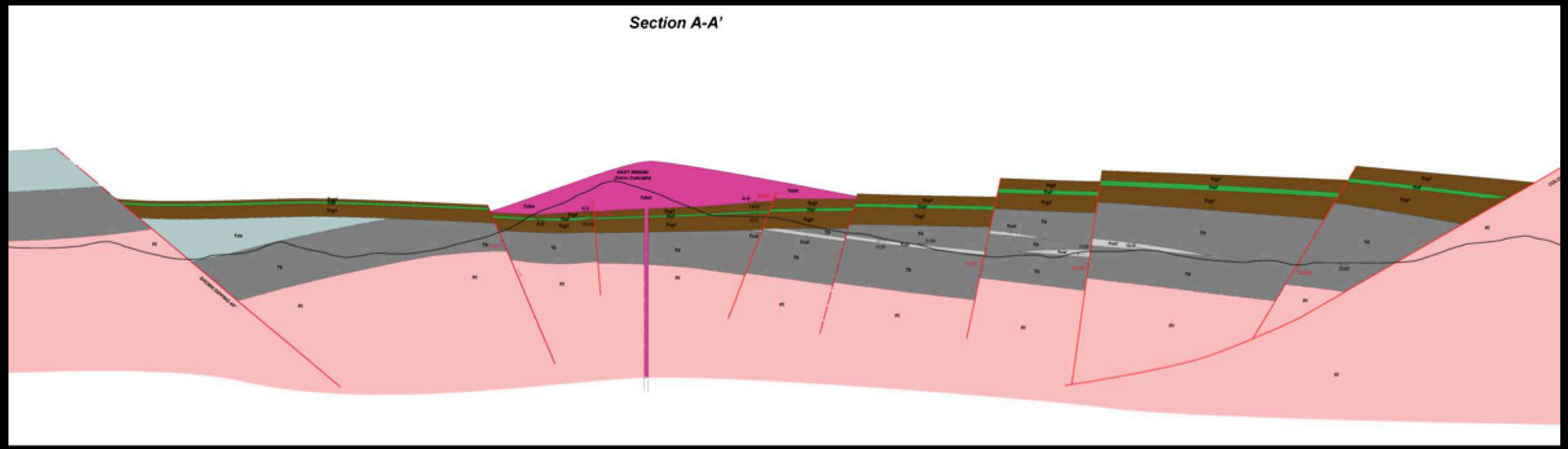


Southern Isla Tiburon

La Cruz fault zone

- Total dextral offset

South Isla Tiburon: Mapping & Geochronology



Bennett et al. (in prep)

~E-W extension ongoing by 12 Ma

onset poorly constrained (post-19Ma)

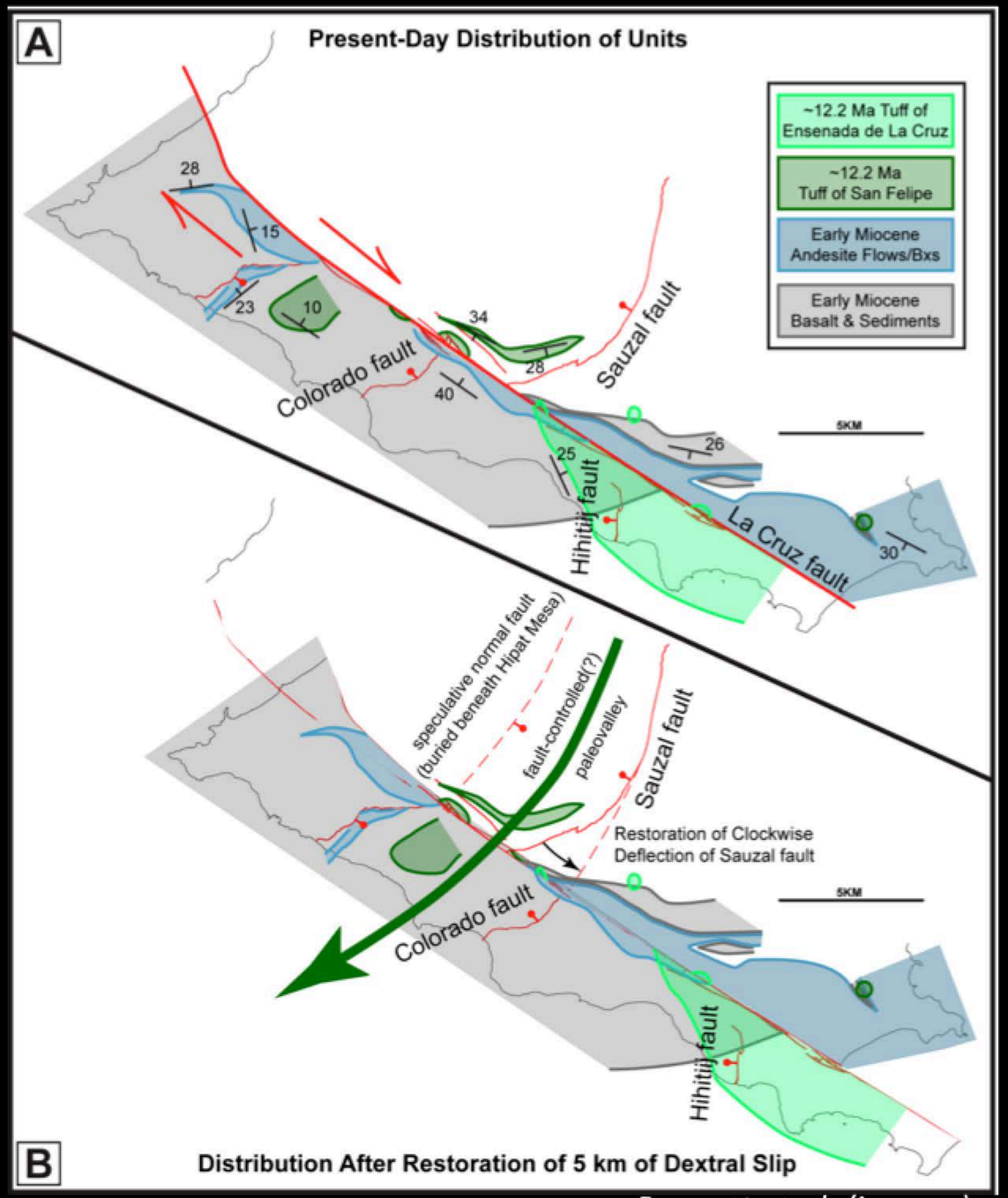
South Isla Tiburon: Mapping & Geochronology

La Cruz fault

5 ± 2 km of dextral displacement restores:

- **5-8 km-wide exposures of ~12 Ma Tuff of San Felipe**
- **Colorado & Sauzal flts**
- **fault-controlled paleo-valley(?)**

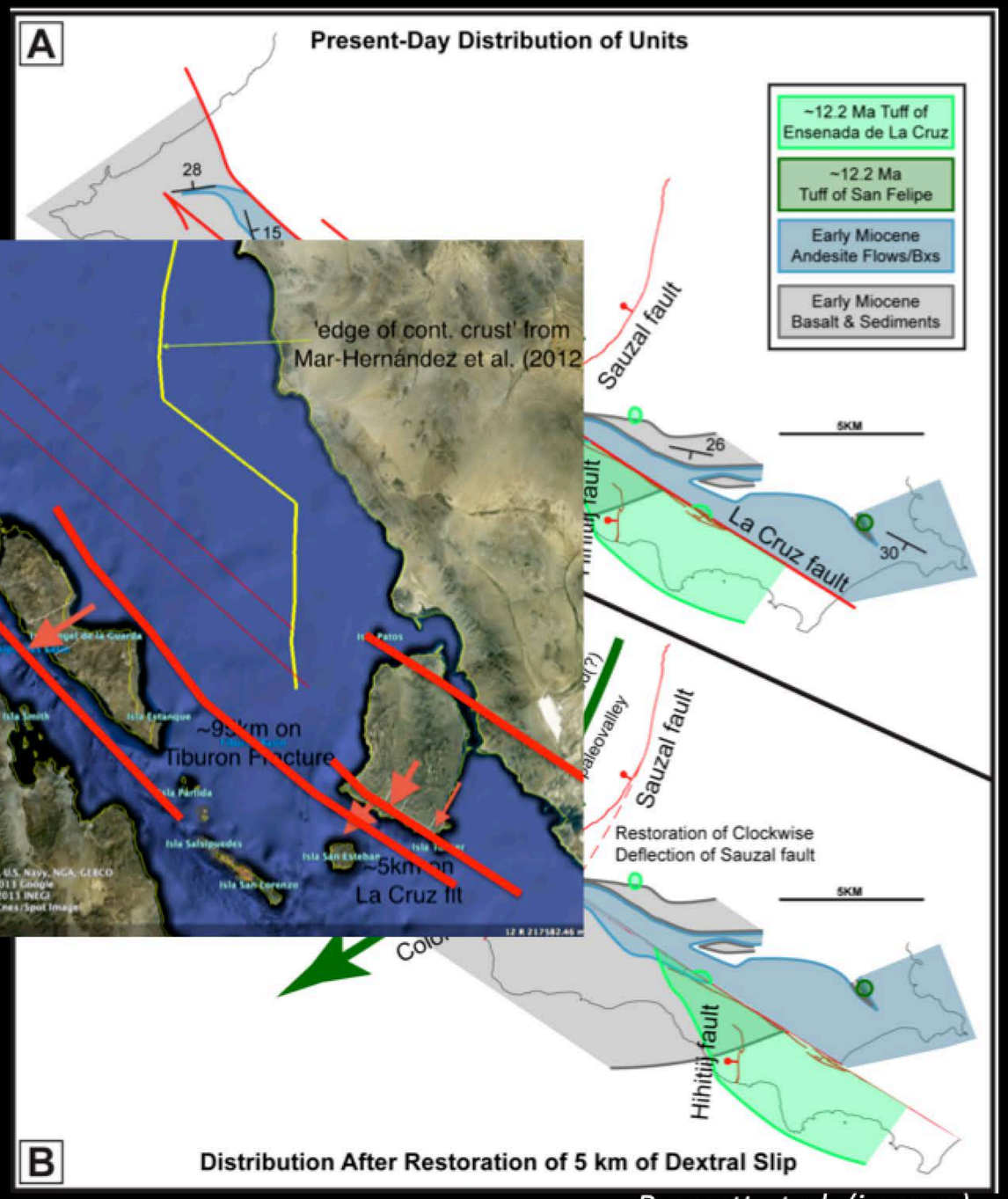
Active 8 - 4 Ma



Bennett et al. (in prep)

South Isla Tiburon: Mapping & Geochronology

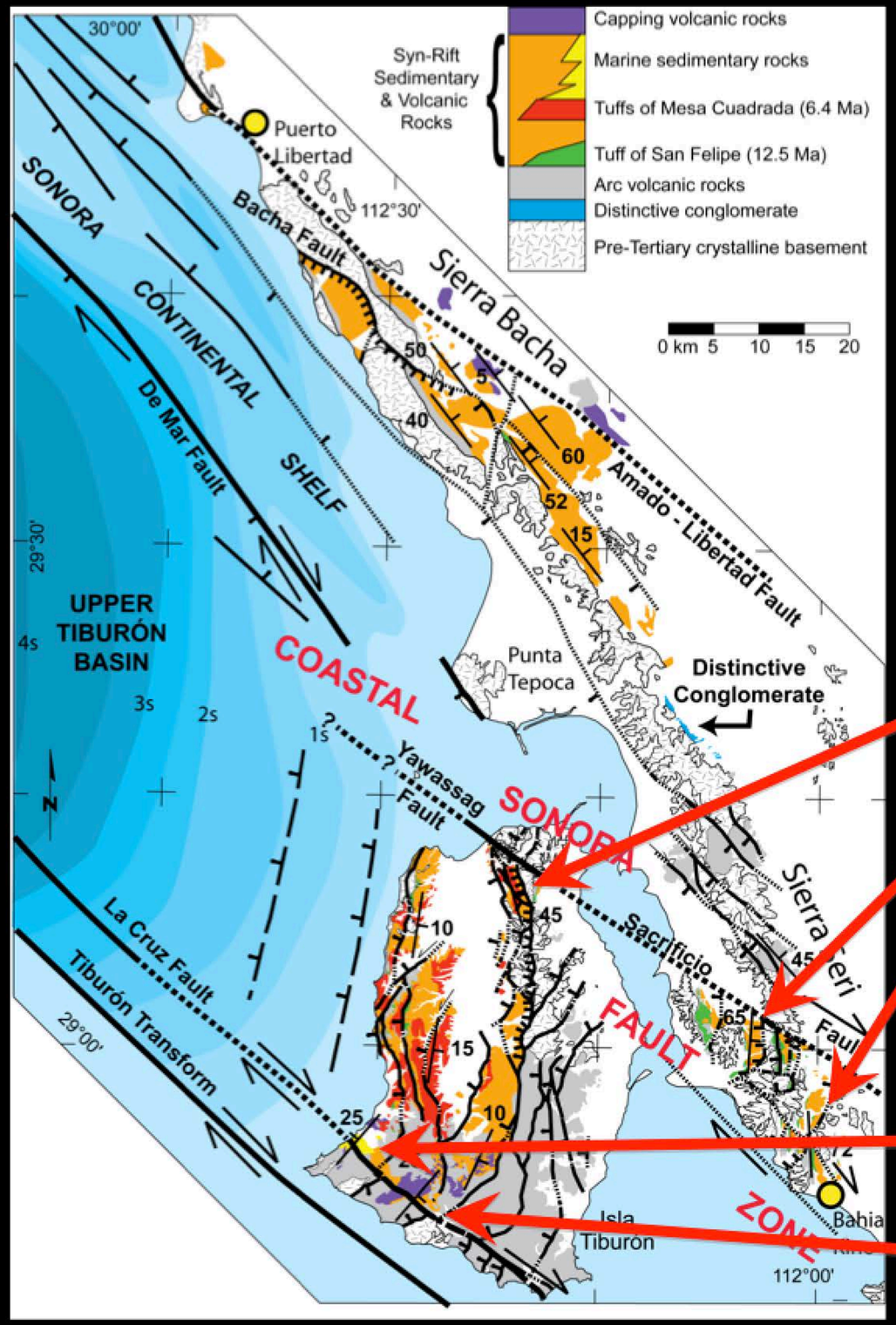
La Cruz fault



Active 8 - 4 Ma

Bennett et al. (in prep)

CONCLUSIONS
Shear Zones Study



Summary of Timing Constraints

Tecomate Basin (~7.0 Ma)

Punta Chueca Basin (~7.0 Ma)

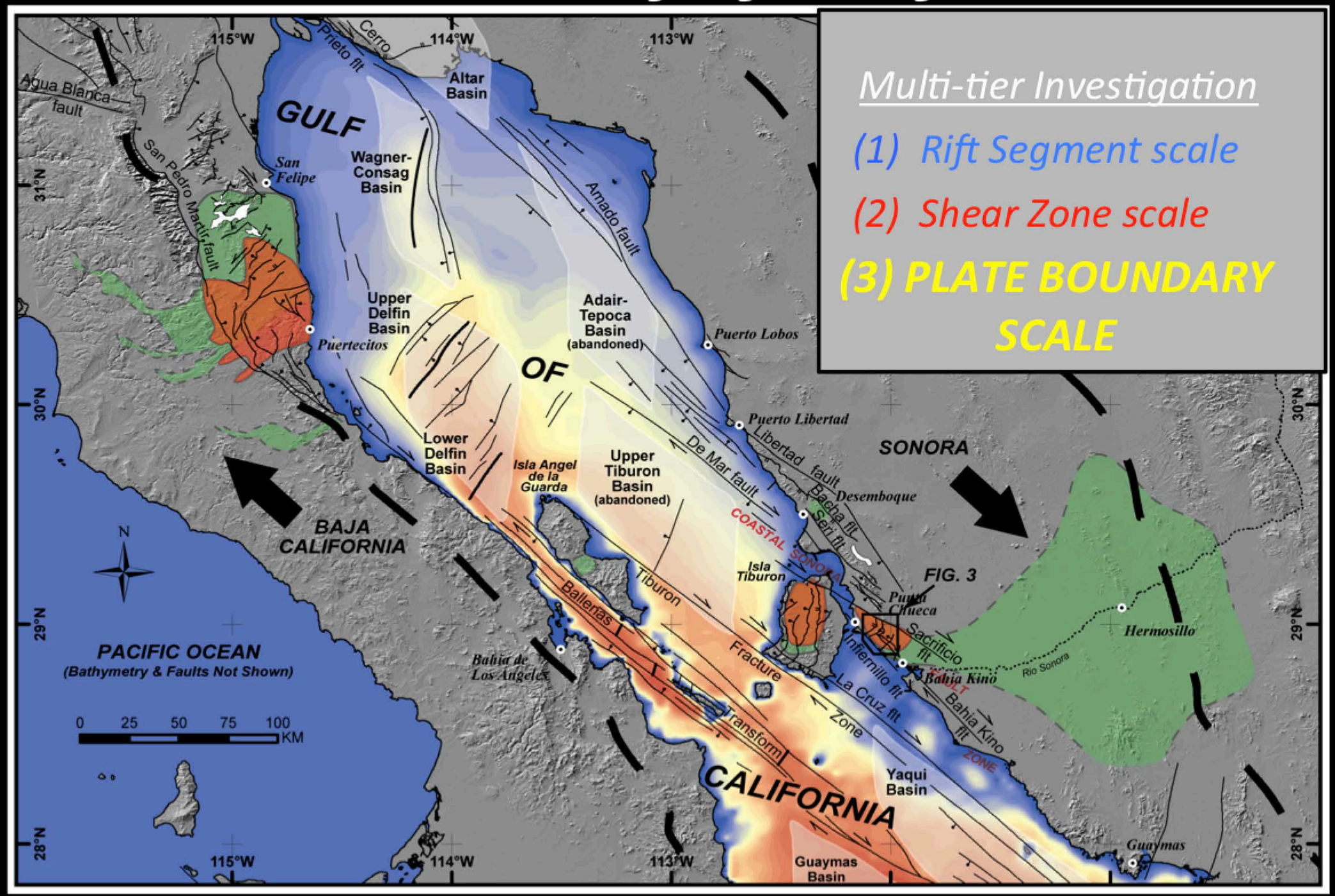
Kino Basin (~7.0 Ma)

Bennett et al. (accepted, GSAB)

SW Isla Tiburon Basin (6.4-6.0 Ma)

La Cruz Basin (~7.9 Ma)

Northern Gulf of California



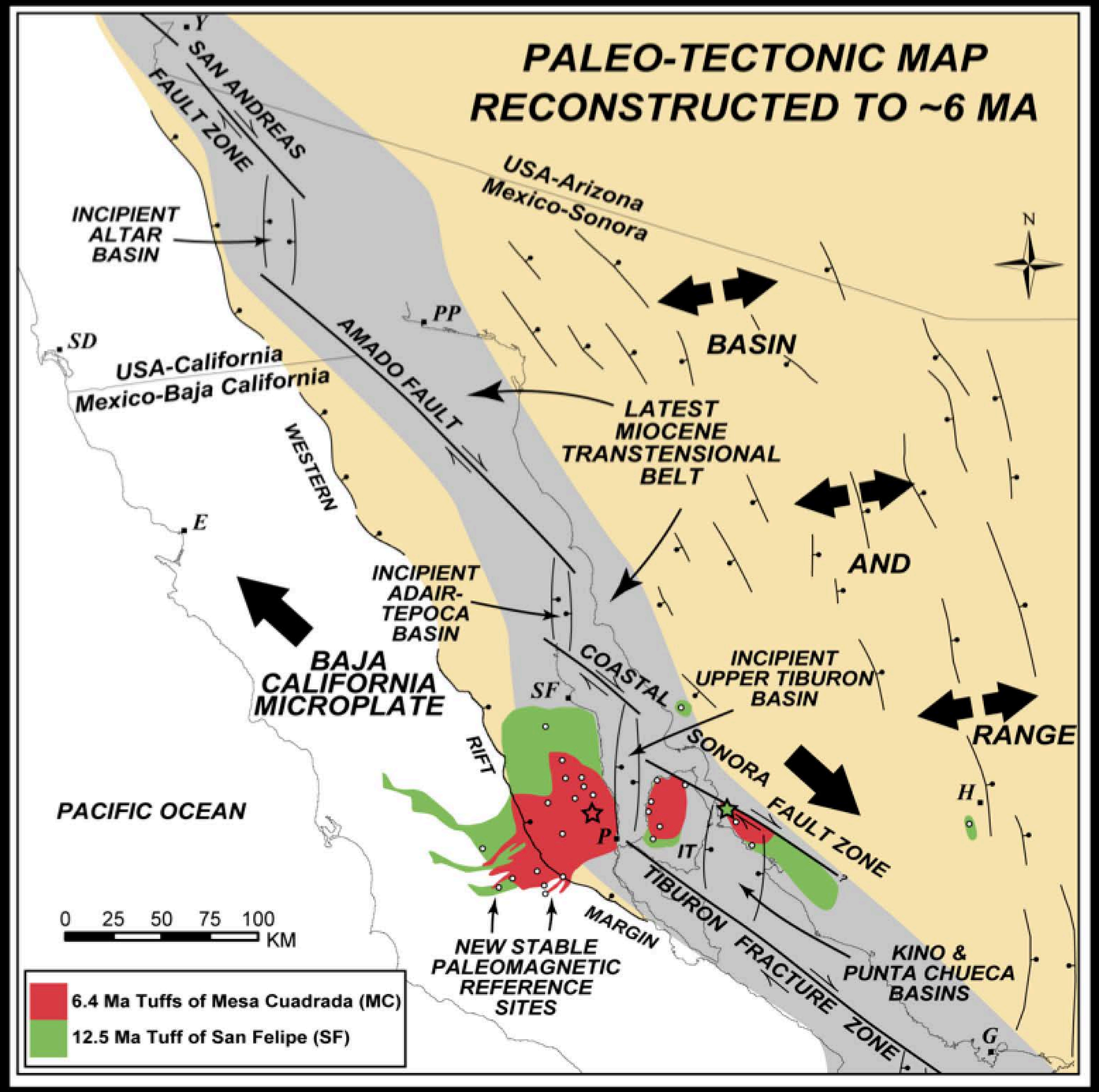
Multi-tier Investigation

(1) Rift Segment scale

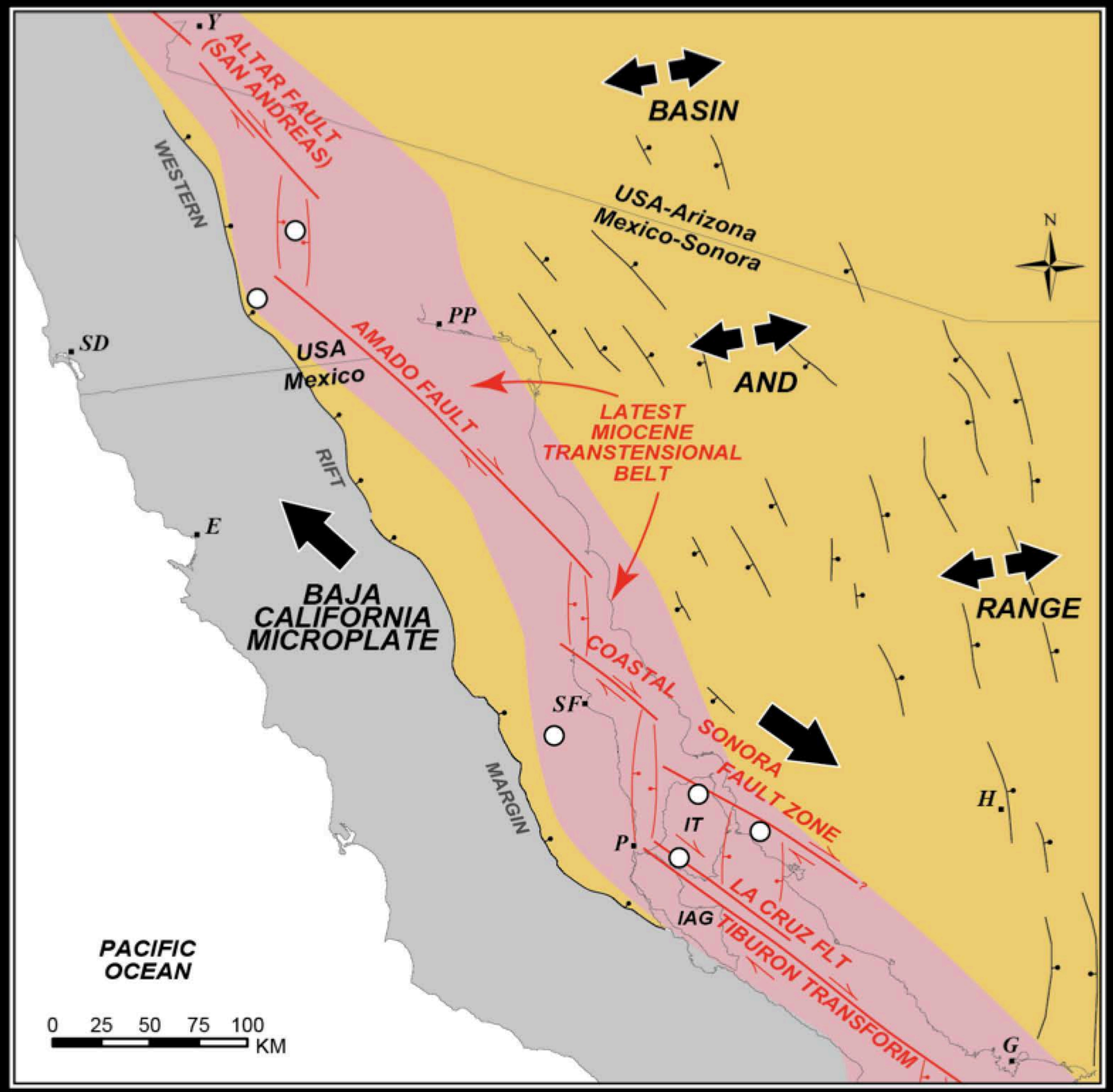
(2) Shear Zone scale

(3) PLATE BOUNDARY SCALE

Results from Rift Segment Paleomagnetic Study



Results from Shear Zones & Tectonic Basins



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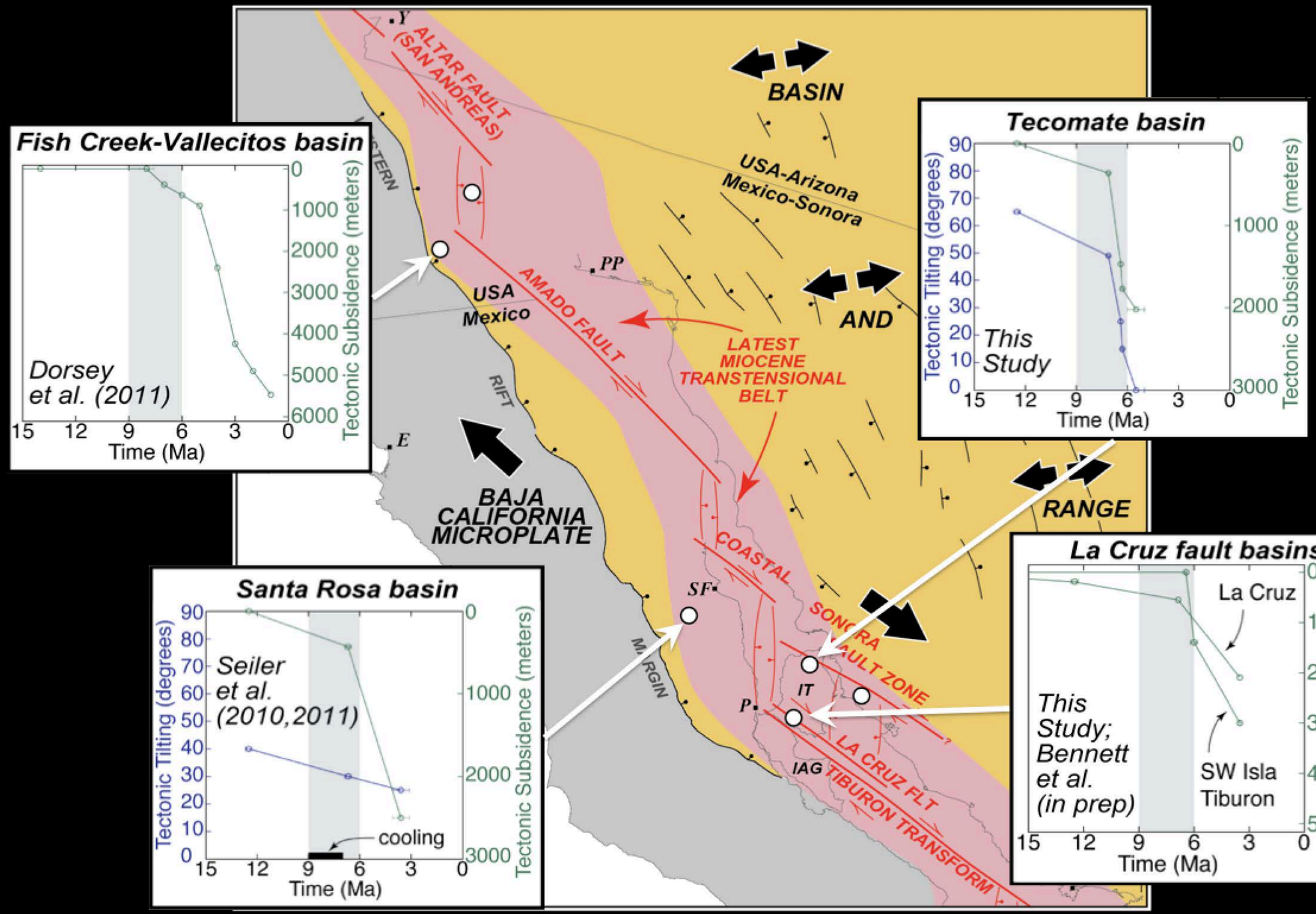


CONCLUSIONS

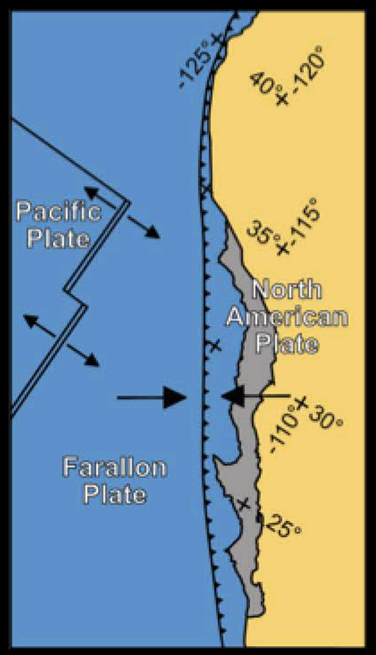
TIME

12.5 Ma ← Proto-Gulf → 6 Ma

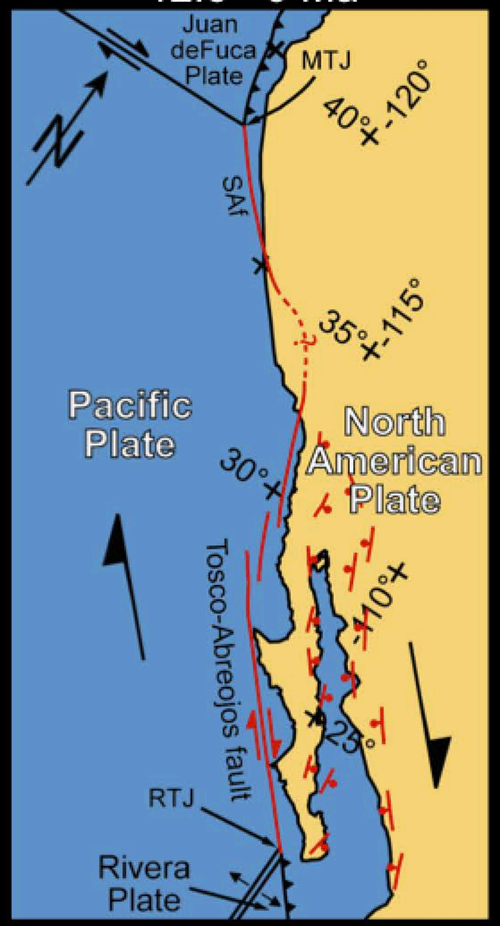
Onset of Significant Dextral Faulting

Strain Localization

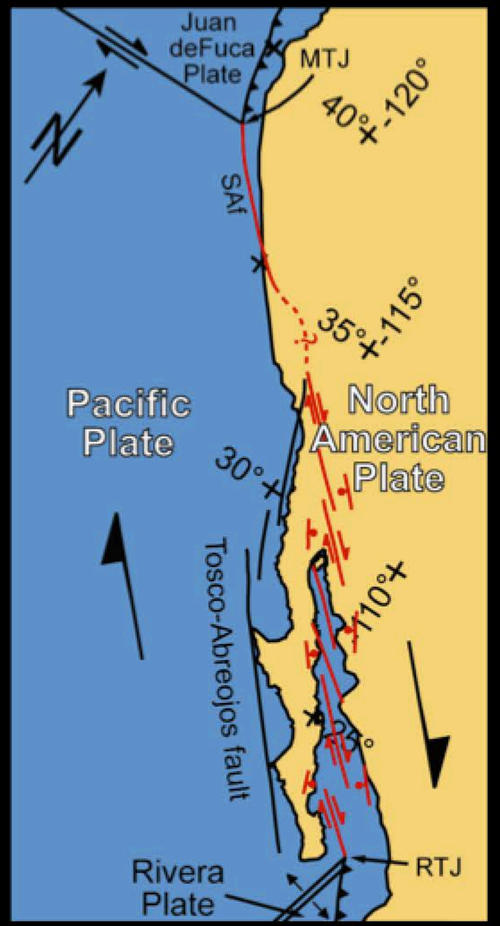
Pre-12.5 Ma



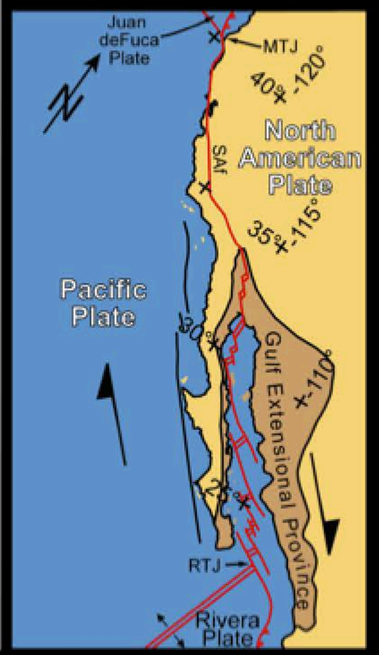
Distributred Transtension (partitioned?) ~12.5 - 9 Ma



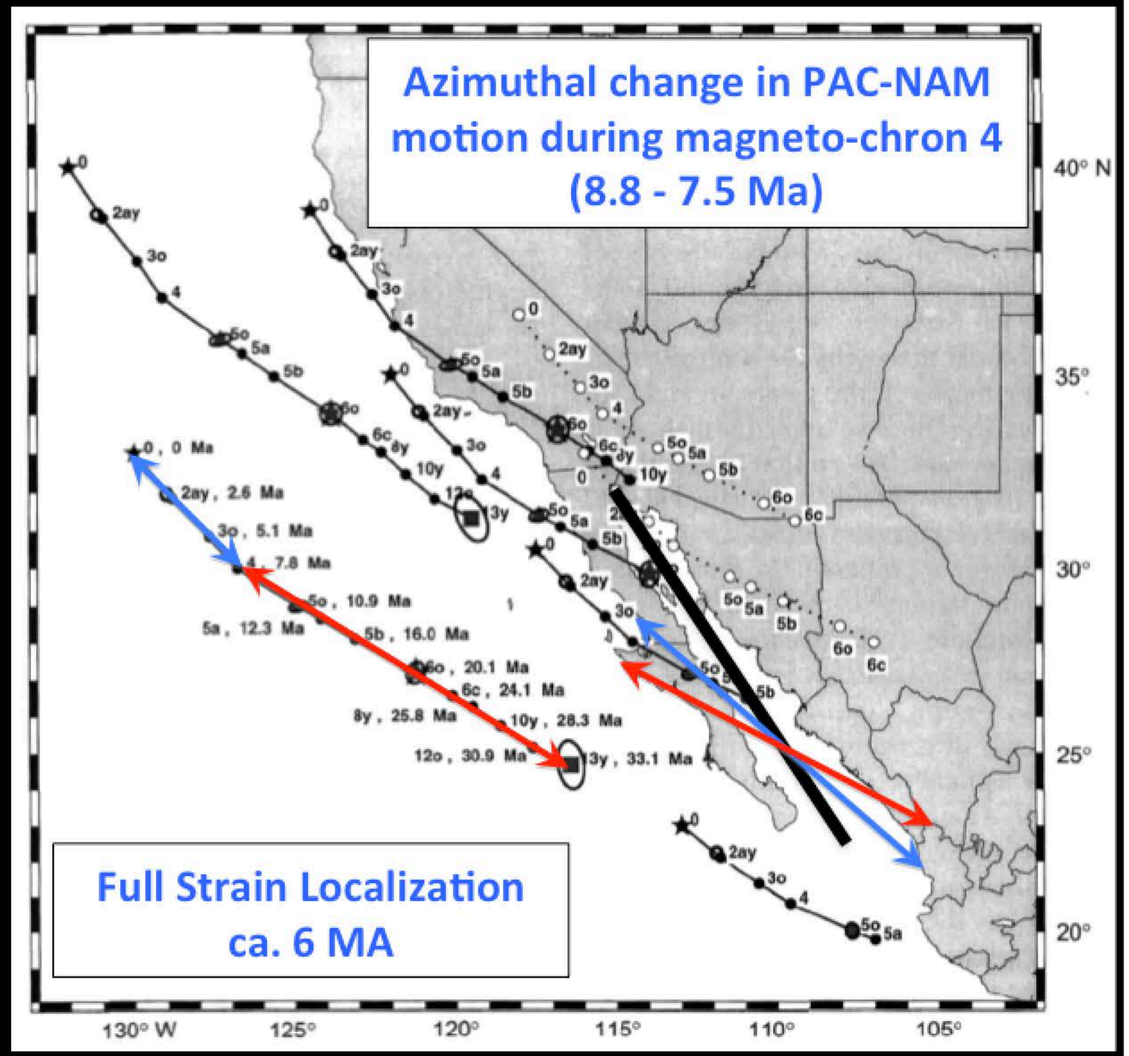
Focused Transtension ~9 - 6 Ma



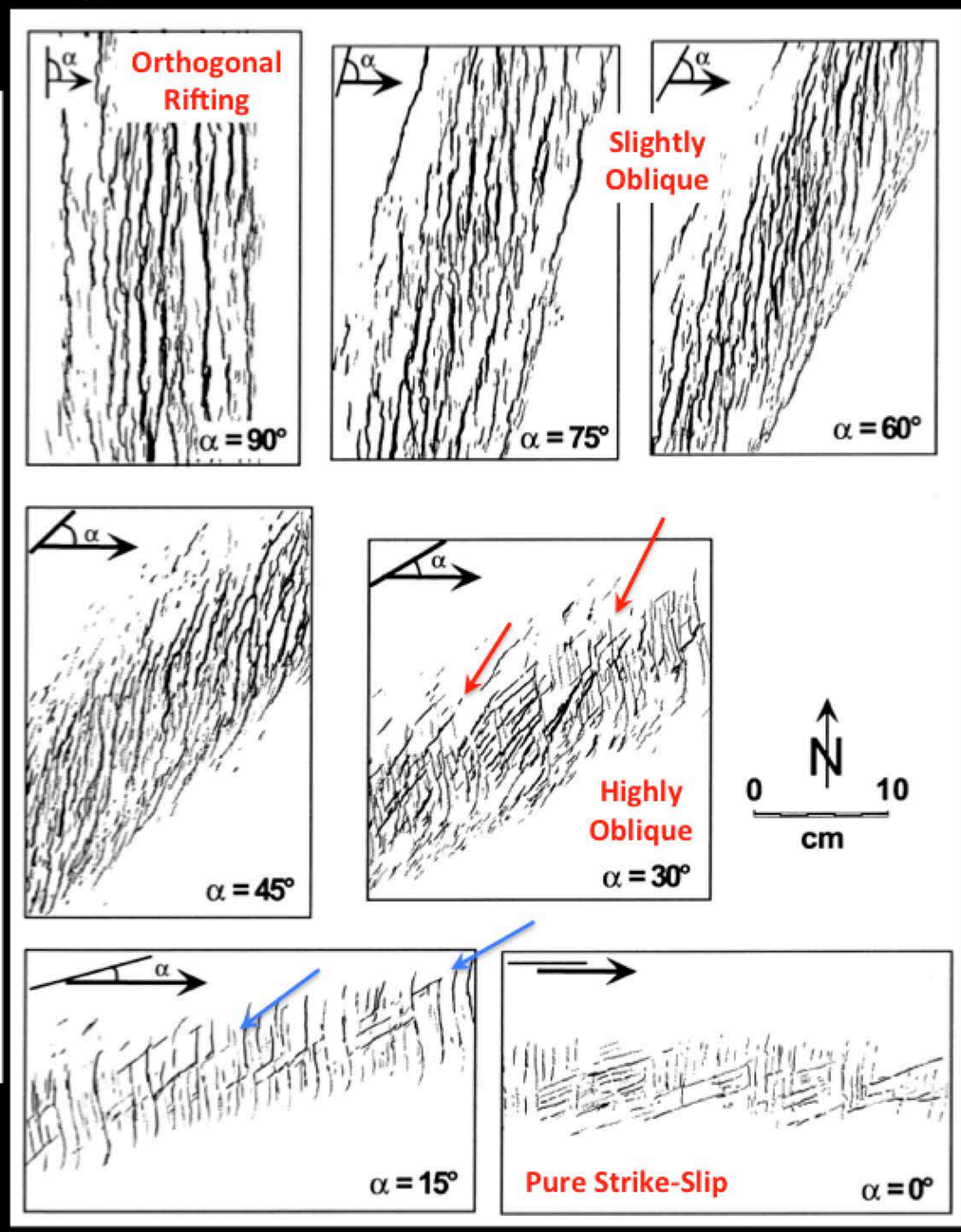
Modern Gulf (6-0 Ma)



Gulf of California

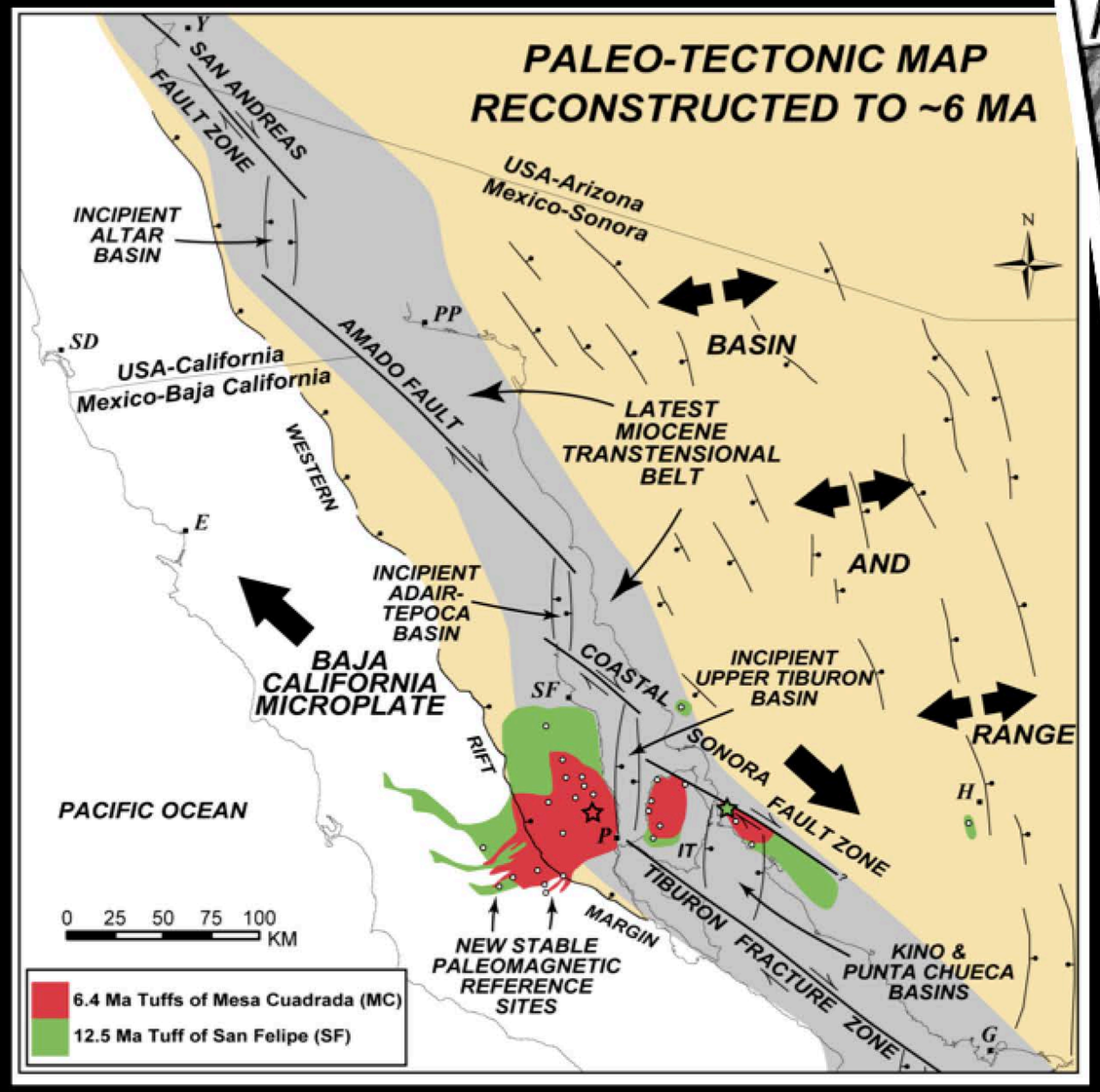


Atwater & Stock (1998)

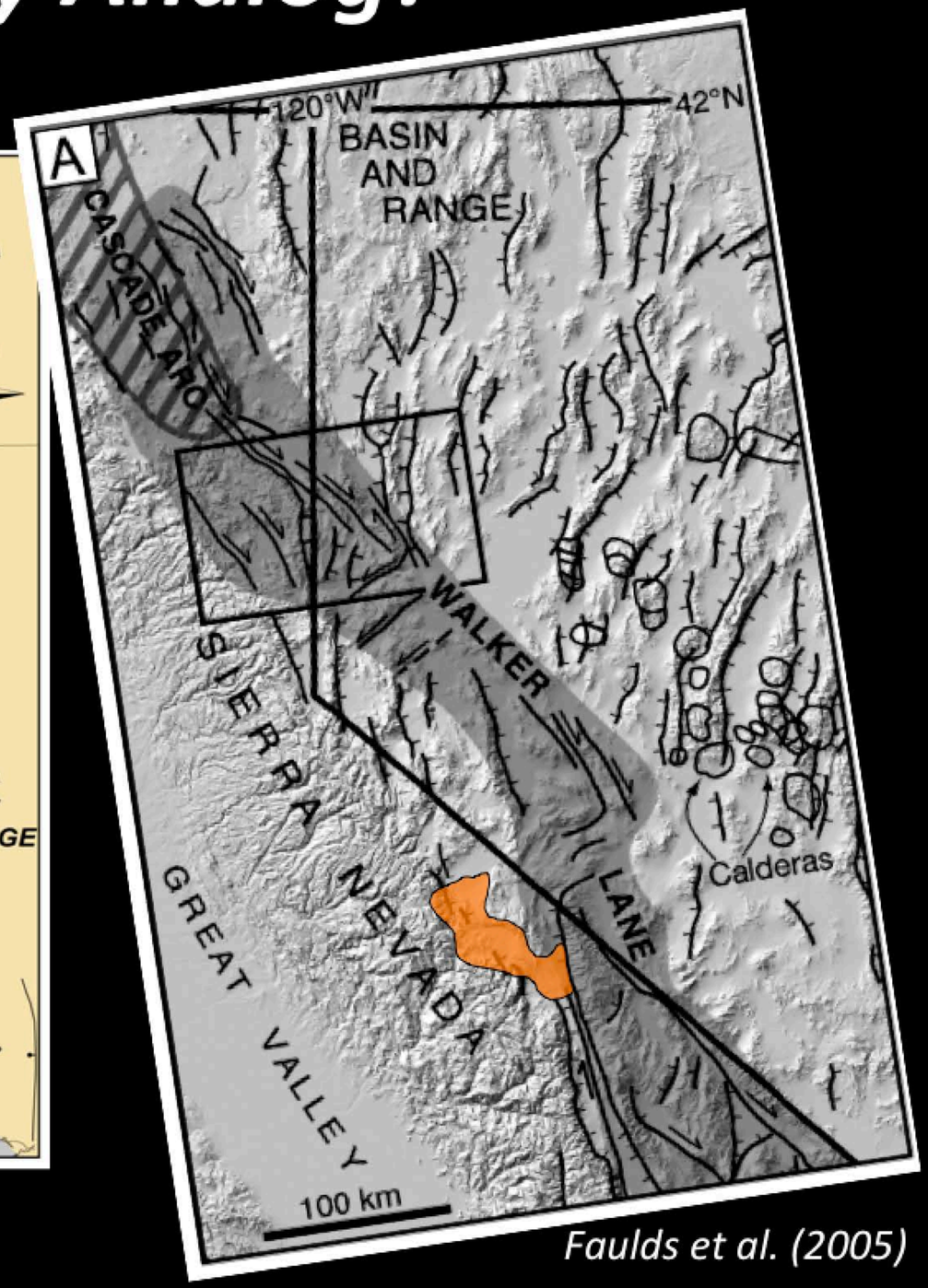


Clifton et al. (2000, 2001)

Modern-day Analog?

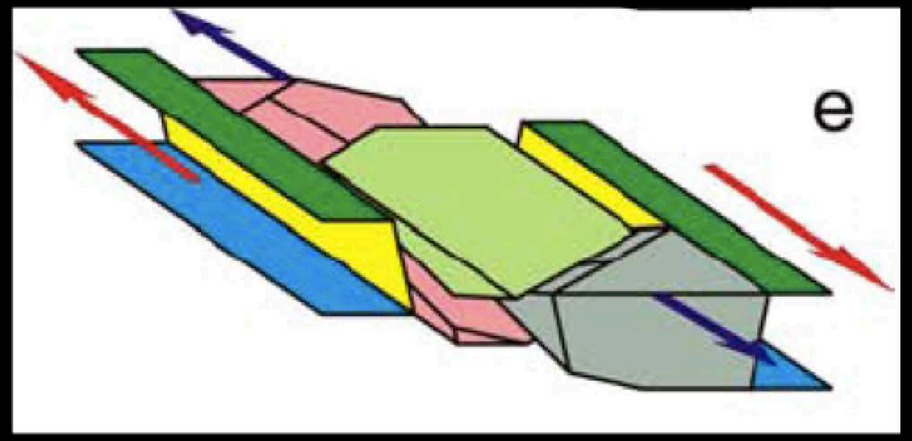


This Study



Faulds et al. (2005)

IMPLICATIONS FOR CONTINENTAL RUPTURE



Aragón-Arreola & Martin-Barajas (2007)

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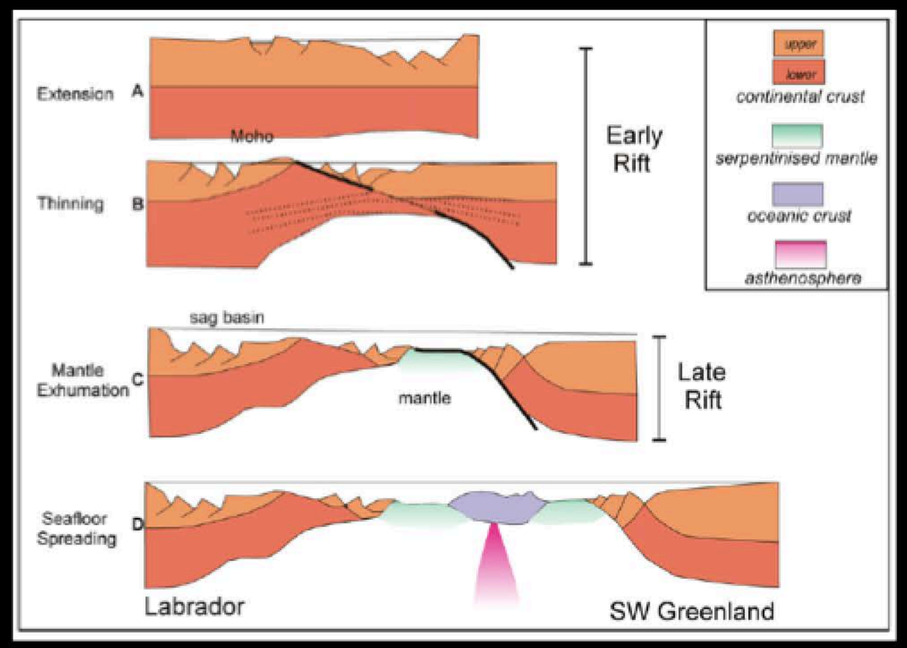
- better than orthogonal rifting

(2) <u>strike-slip faults</u> likely play a role in localization of extensional strain



Dickie et al. (2011)
Chian et al. (1995)

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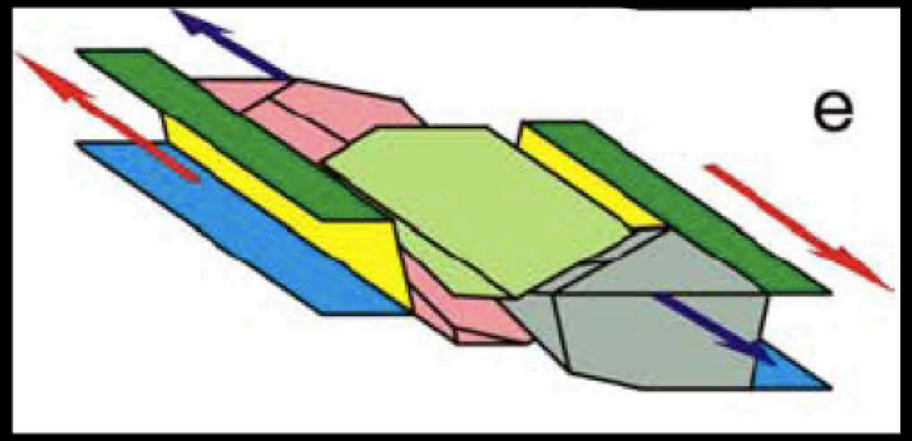

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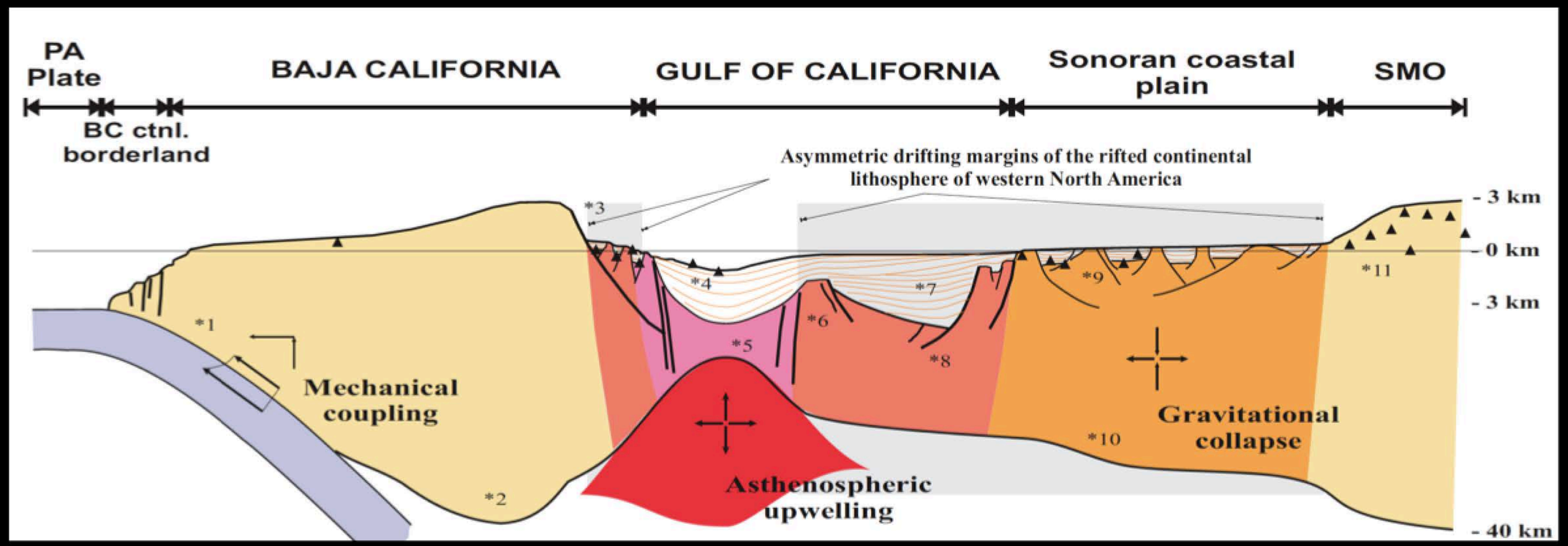

Aragón-Arreola & Martín-Barajas (2006)

ACKNOWLEDGMENTS

Mapping Shear Zones

Ernesto Molina (family and Seri tribe), Molly Keogh, Nick Buckmaster, Becky Dorsey, Prescott College Kino Bay Center

Paleomagnetic Study

Mike Darin, Joe Kirschvink, Raub, Steve Skinner, Sarah Slotznick, Joann Stock, Arturo Martín-Barajas

Plate Boundary Reconstruction

Lisa Skinner, Paul Umhoefer, Mike Darin, Becky Dorsey, Jared Kluesner, Richard Nava, Gary Axen

Field Assistants

ACKNOWLEDGMENTS

Monica Iglecia

Michael Tappa

Dhelia Tucker

Eric Stevens

Anne Gauer

Dan Hadley

Karen Bossenbroek

Jordan Ford


Thank you.