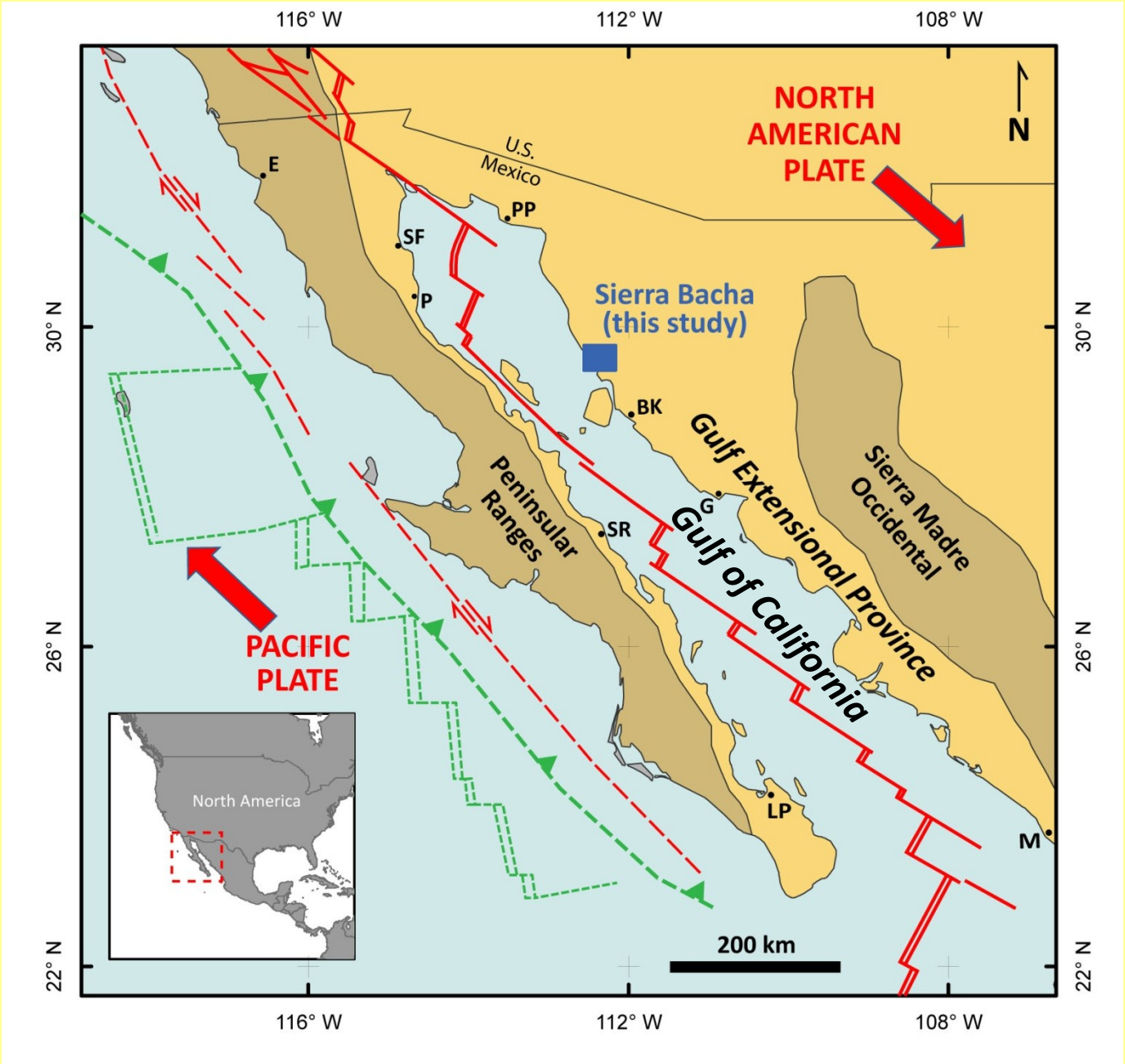
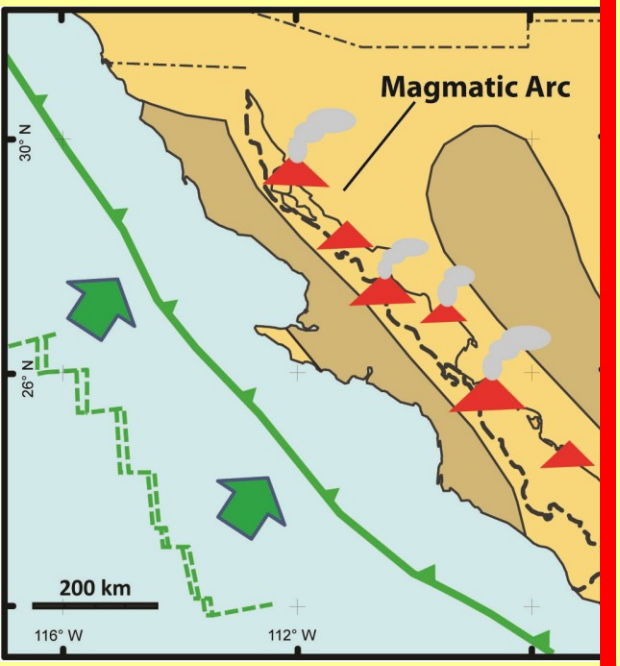
Late Miocene Extensional Deformation in the Sierra Bacha, coastal Sonora, Mexico: Implications for the Kinematic Evolution of the Proto-Gulf of California

Michael Darin* & Rebecca Dorsey - *University of Oregon, USA*
Scott Bennett & Michael Oskin - *University of California-Davis, USA*
Alexander Iriondo - *Universidad Nacional Autónoma de México*

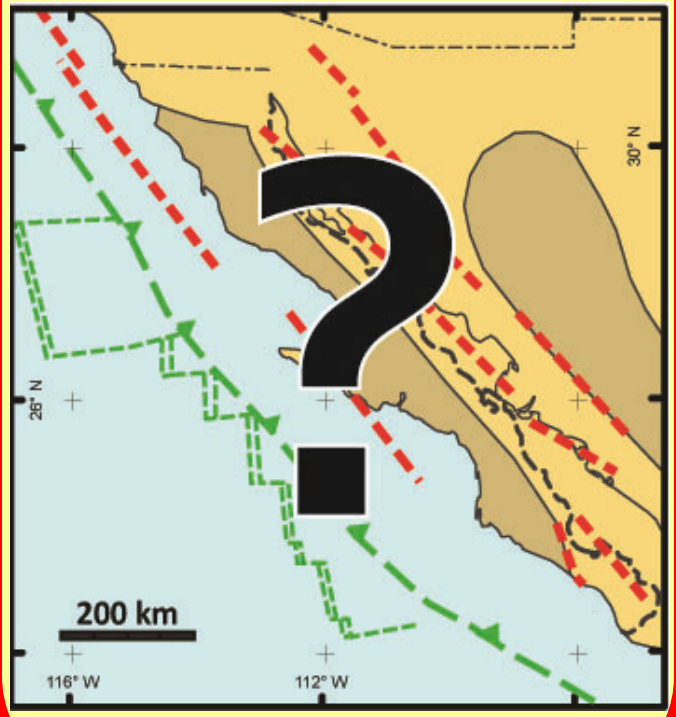
Gulf of California Rift



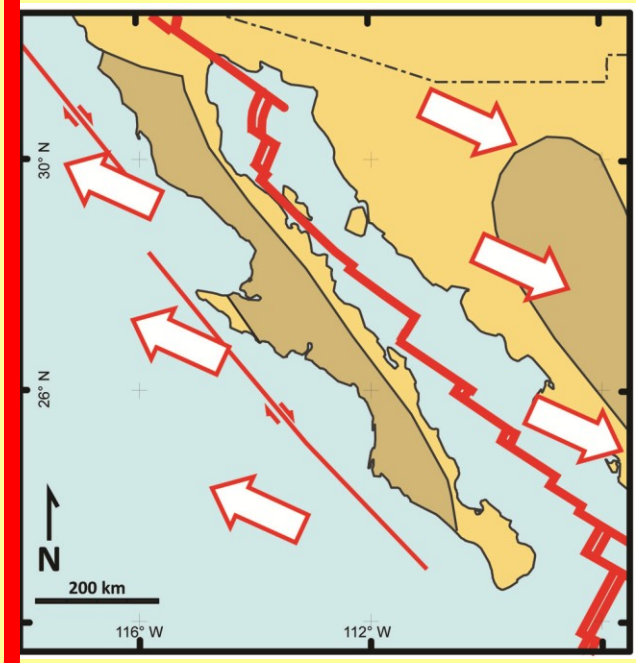
Pre-12 Ma
Convergent margin



12-6 Ma
"Proto-Gulf"
phase



Post-6 Ma
Modern oblique
rifting

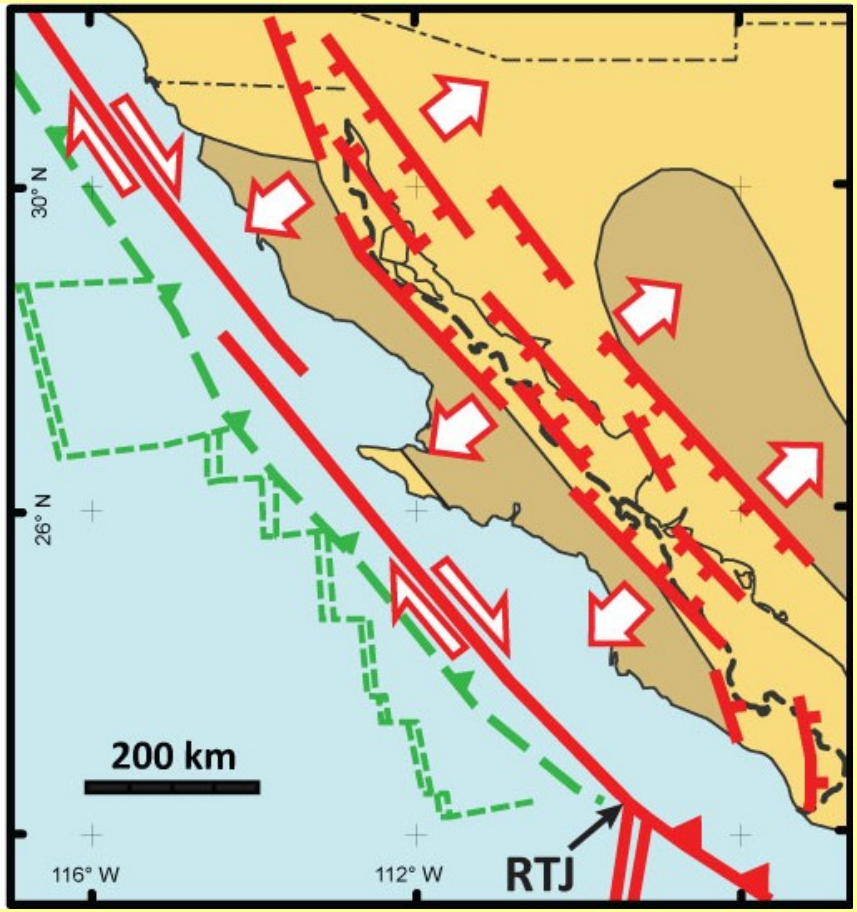


TIME

Kinematic Models for Proto-Gulf (12-6 Ma) Evolution

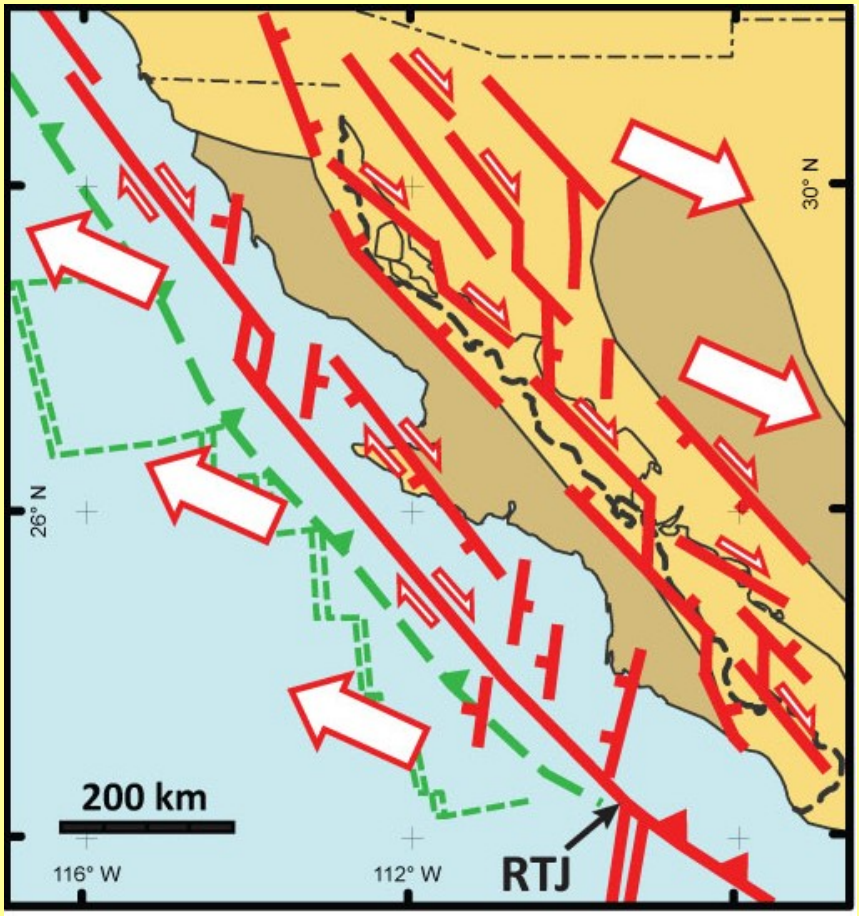
Strain Partitioning

(e.g. Hausback, 1984, Stock and Hodges, 1989)



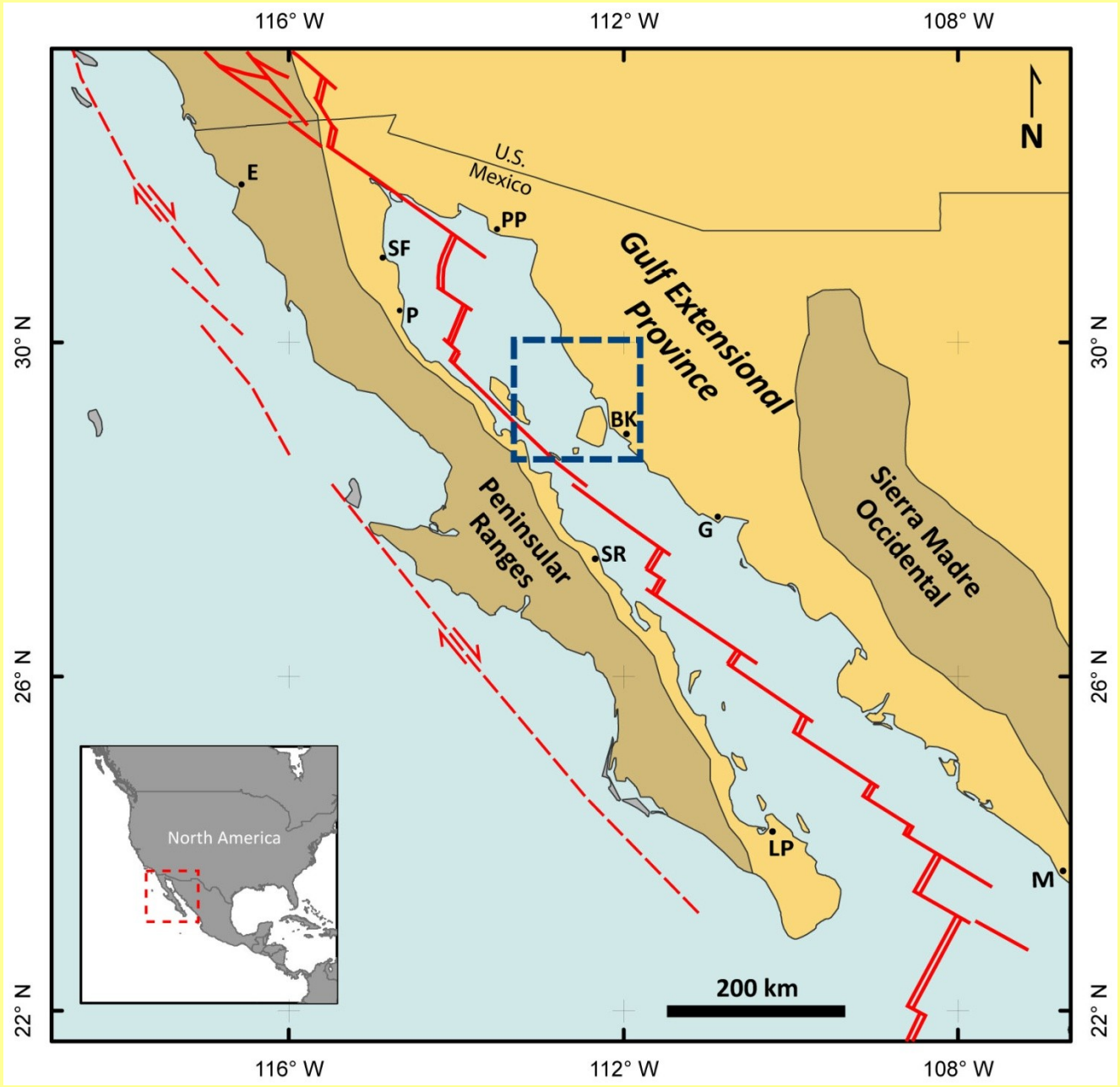
Distributed Transtension

(e.g. Fletcher et al., 2003, 2007; Seiler et al., 2010)



Traditional end-member models

Coastal Sonora Study Area



Coastal Sonora Study Area

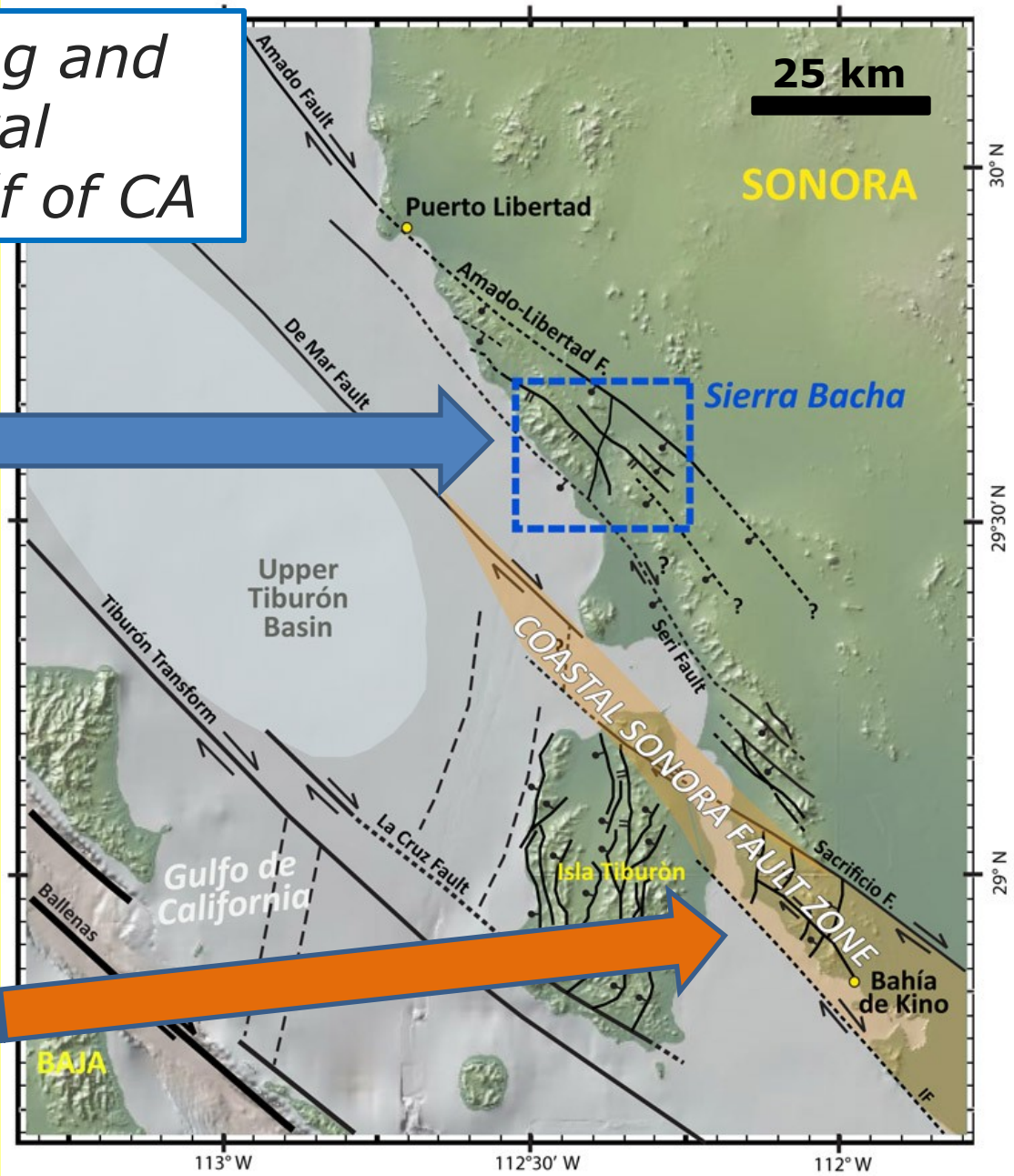
Goal: *Investigate timing and kinematics of continental rupture in northern Gulf of CA*

Sierra Bacha

- *15-6 Ma volcanics record proto-Gulf deformation*
- *Rare opportunity to investigate rift kinematics on eastern rift margin*
- *Adjacent to well-documented latest Miocene dextral shear*

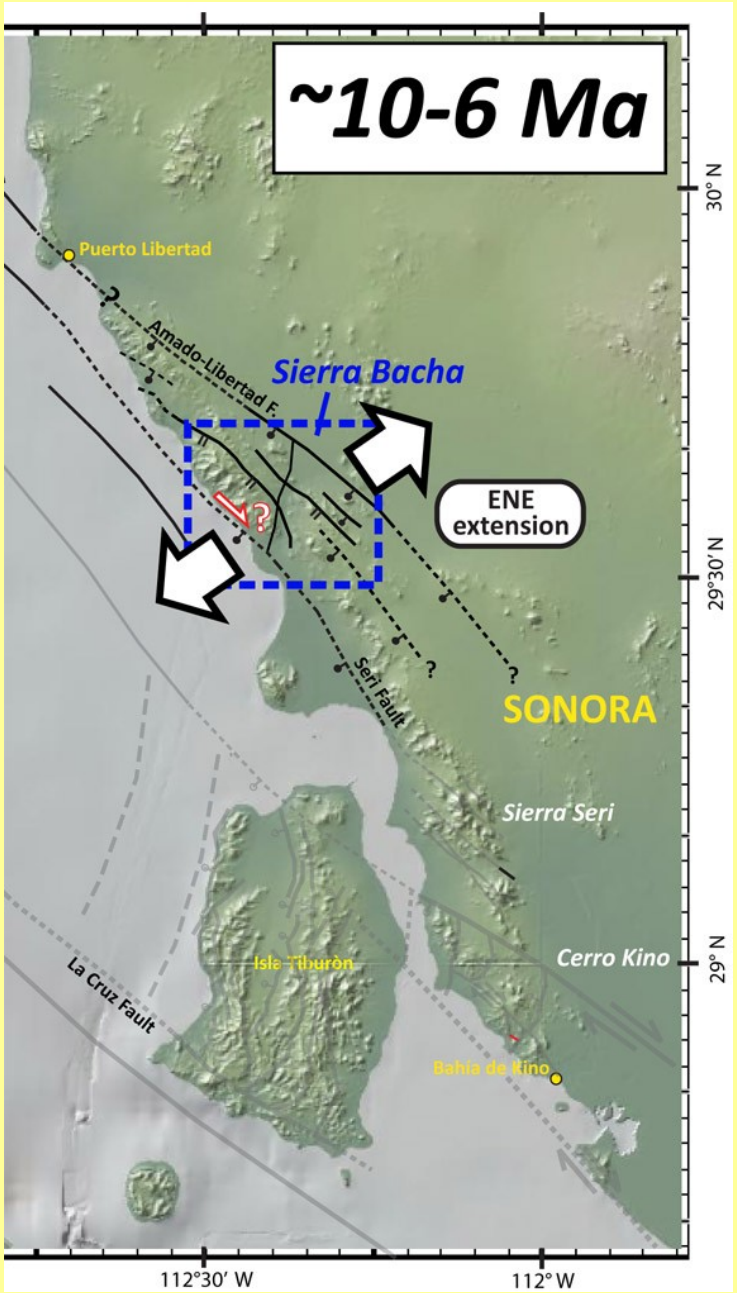
Coastal Sonora F.Z.

- *minimum 14 km dextral strain ca. 7-6 Ma*
- ***(next talk by Bennett, S.E.K.)***

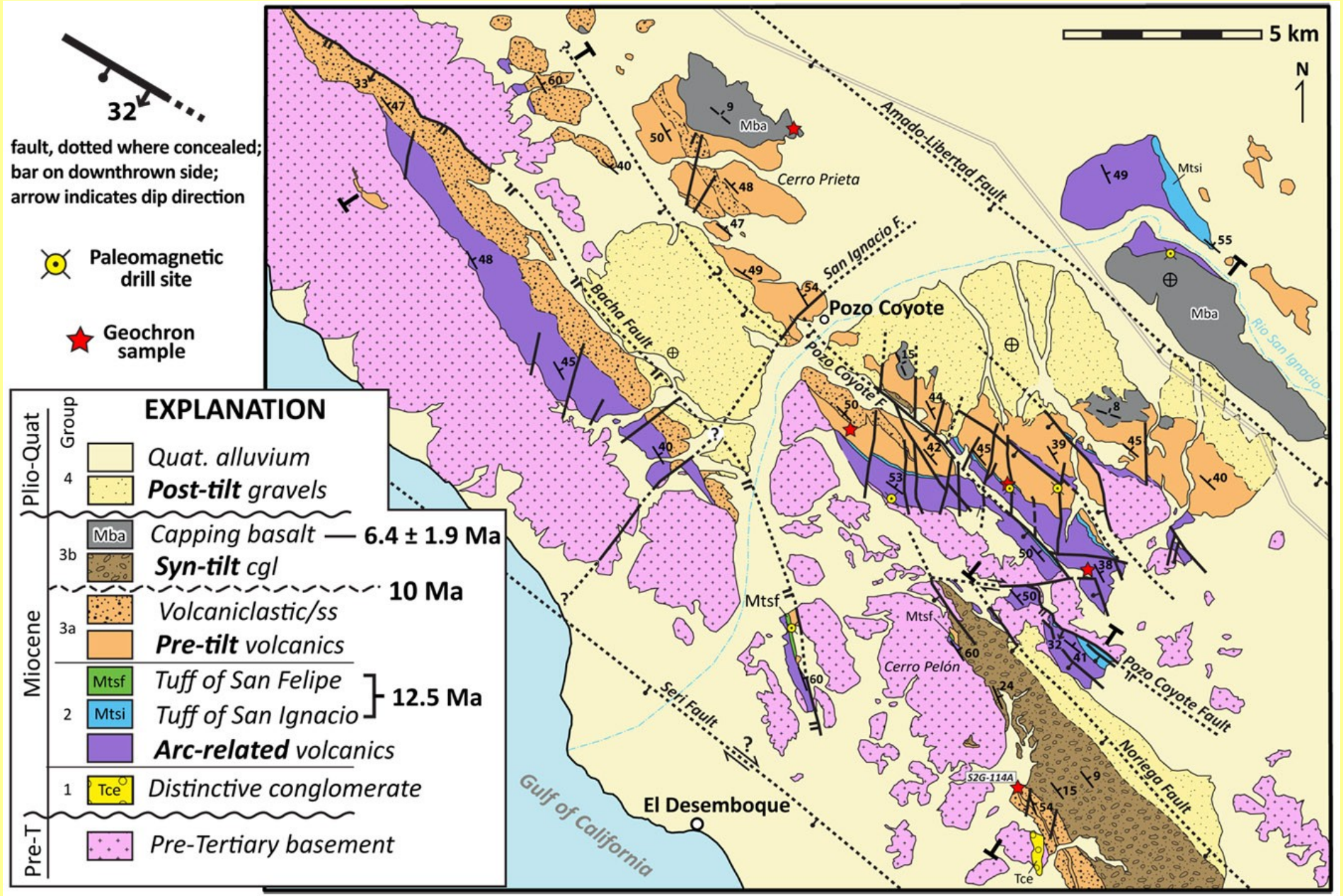


Sierra Bacha Results:

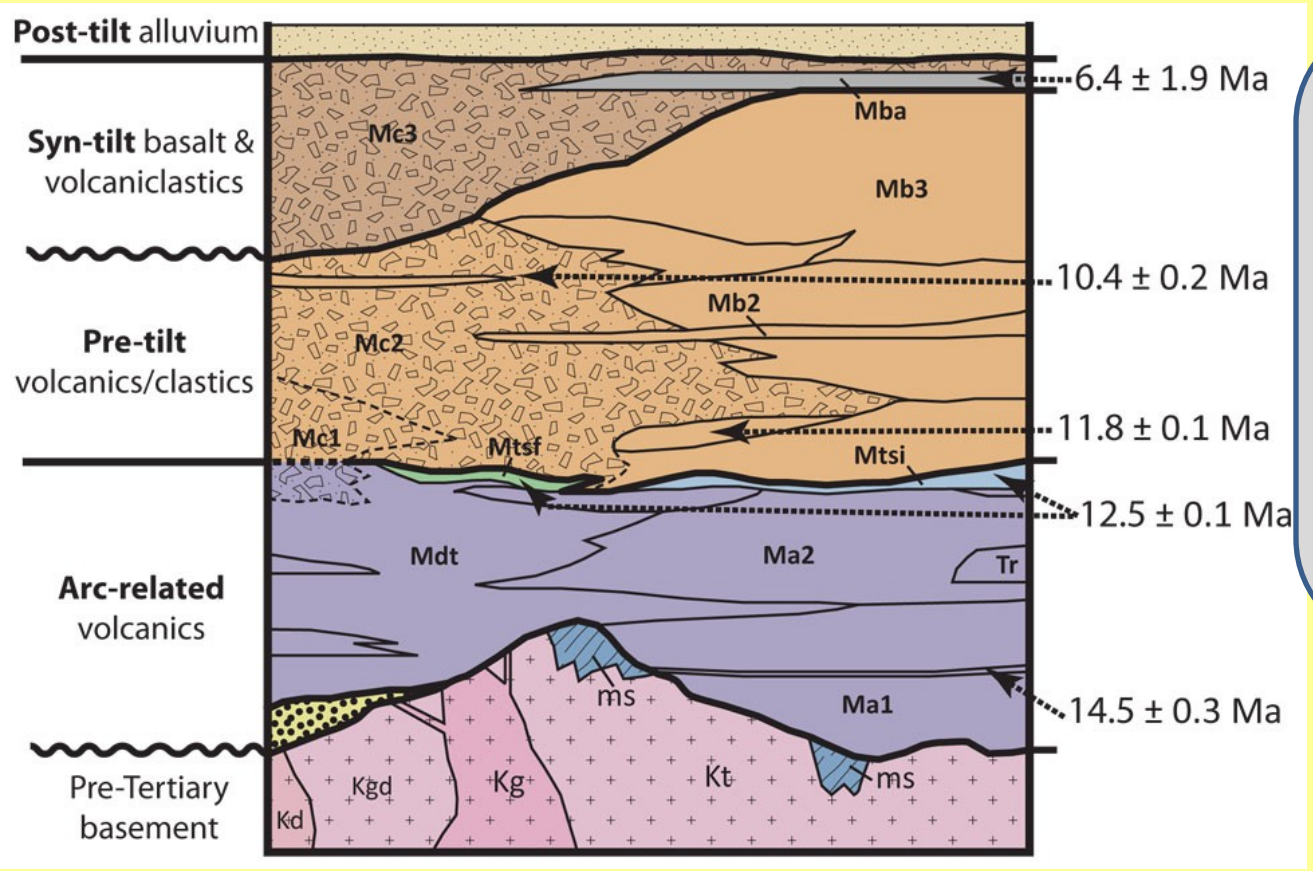
- ENE-directed extension from ~10-6 Ma
- Little to no dextral shear during proto-Gulf time



The Sierra Bacha - Overview



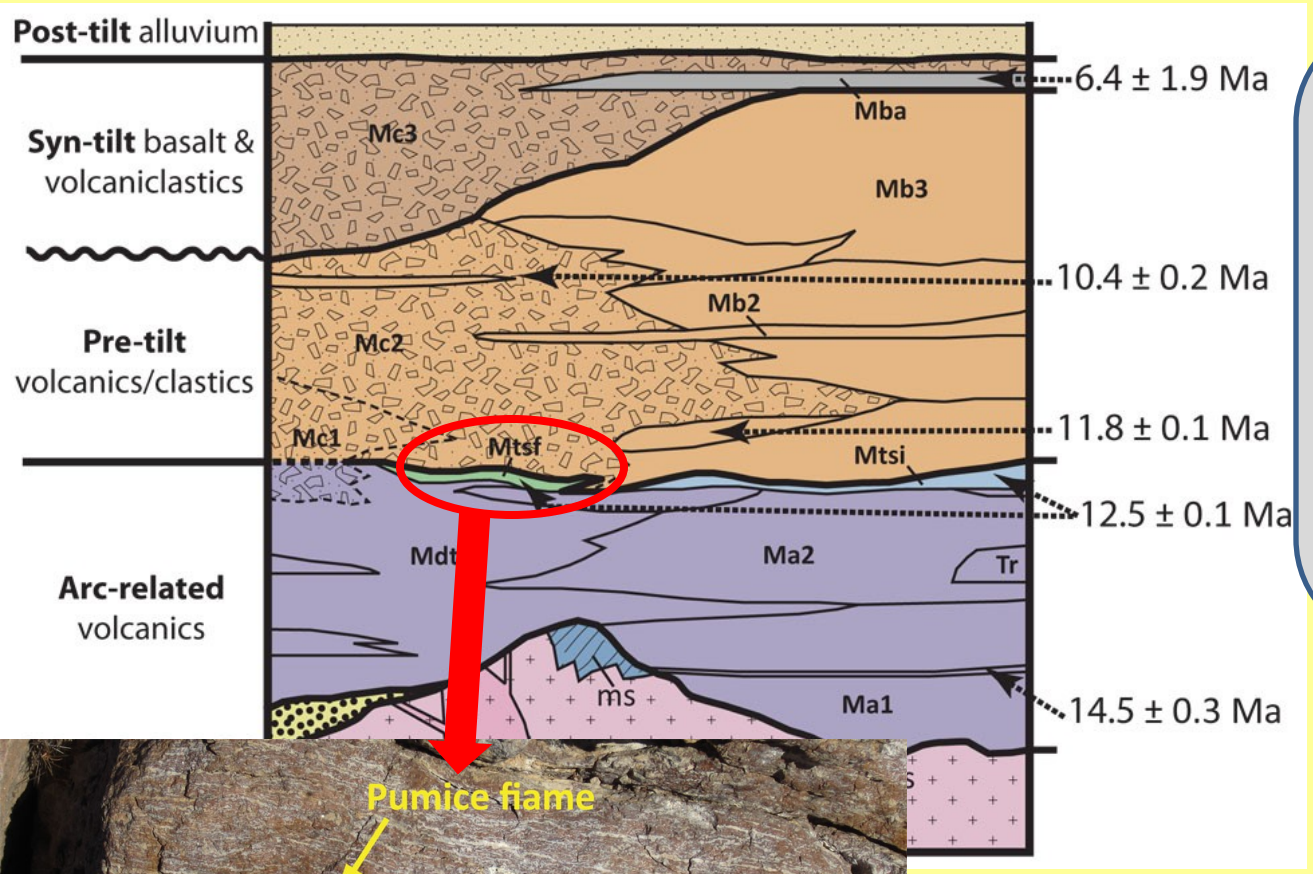
The Sierra Bacha - Stratigraphy



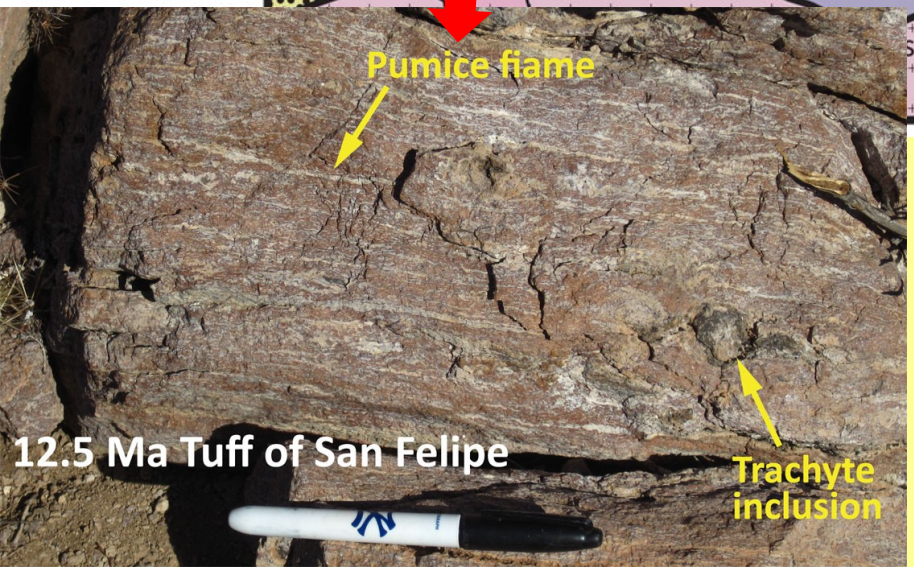
- 2.5 km-thick volcanic section
- Fanning dip (30-0º) in 10-6 Ma "Syn-tilt" units
- 15-10 Ma "Pre-tilt" units dip 40-60º NE

(Isotopic ages by A. Iriondo, unpub. data)

The Sierra Bacha - Stratigraphy

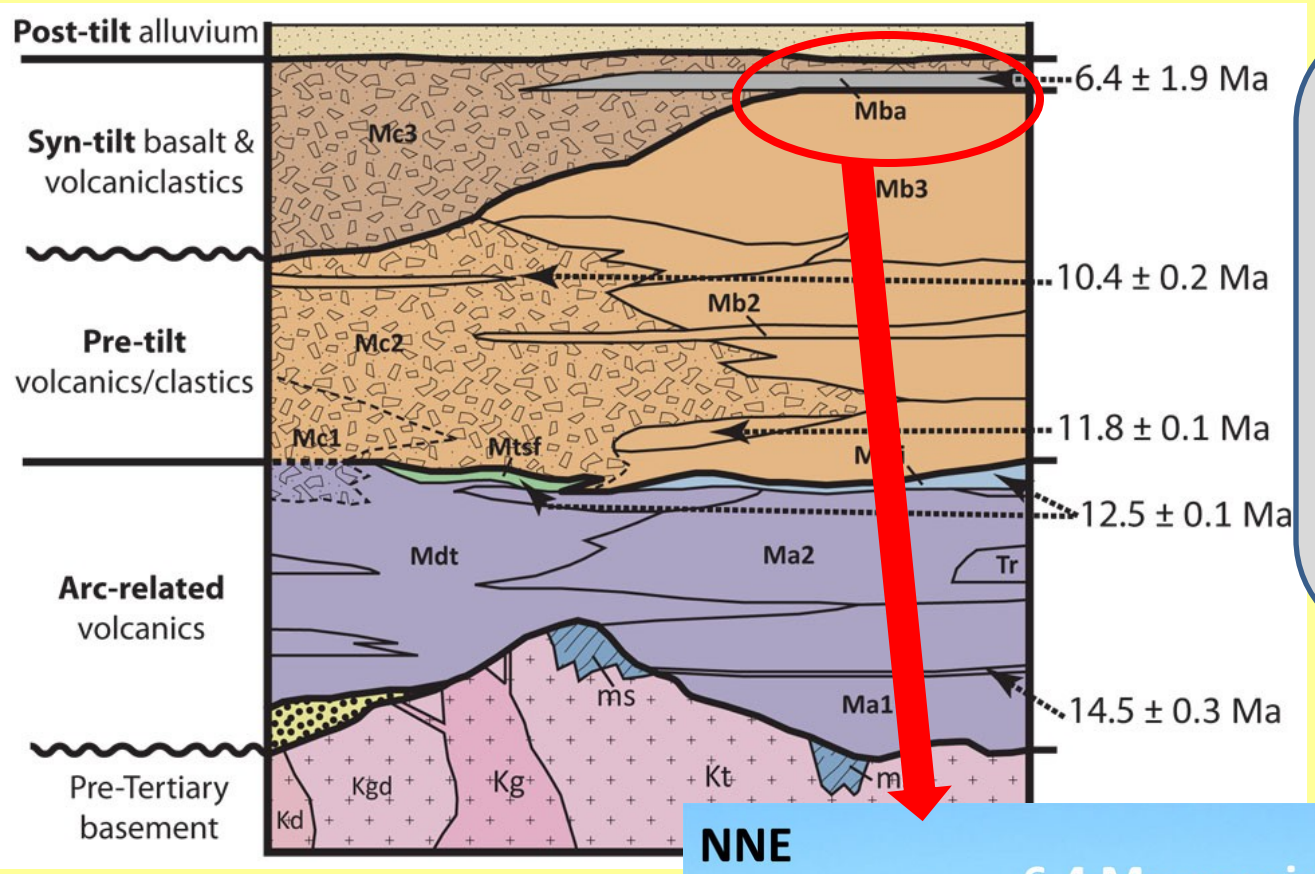


- 2.5 km-thick volcanic section
- Fanning dip (30-0º) in 10-6 Ma "Syn-tilt" units
- 15-10 Ma "Pre-tilt" units dip 40-60º NE

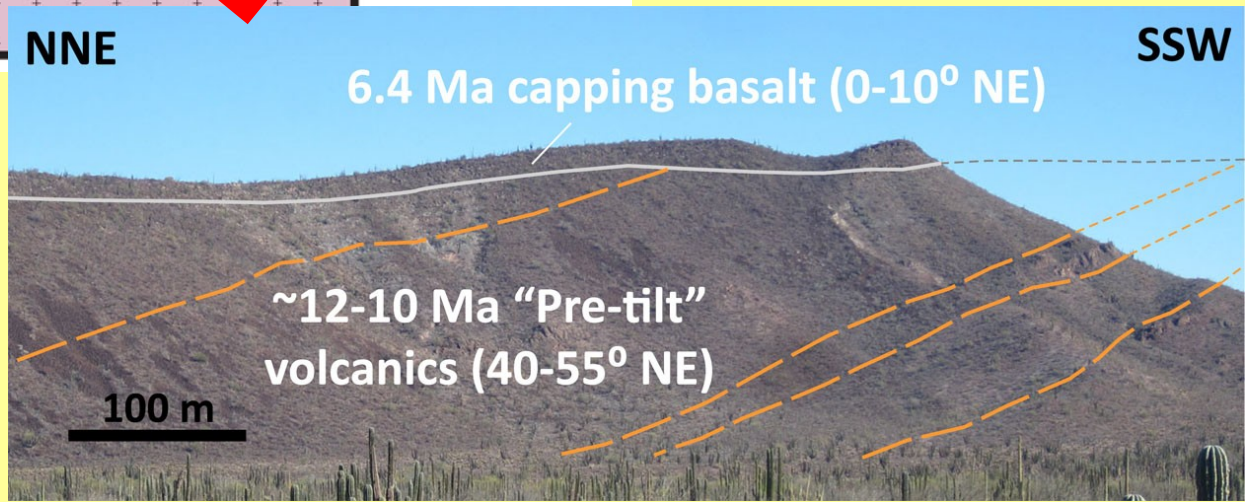


- 12.5 ± 0.1 Ma [U/Pb]
- Distinctive fiamé and inclusions
- 25-70 m-thick in Sierra Bacha
- Extensive ignimbrite marker on Baja and in coastal Sonora

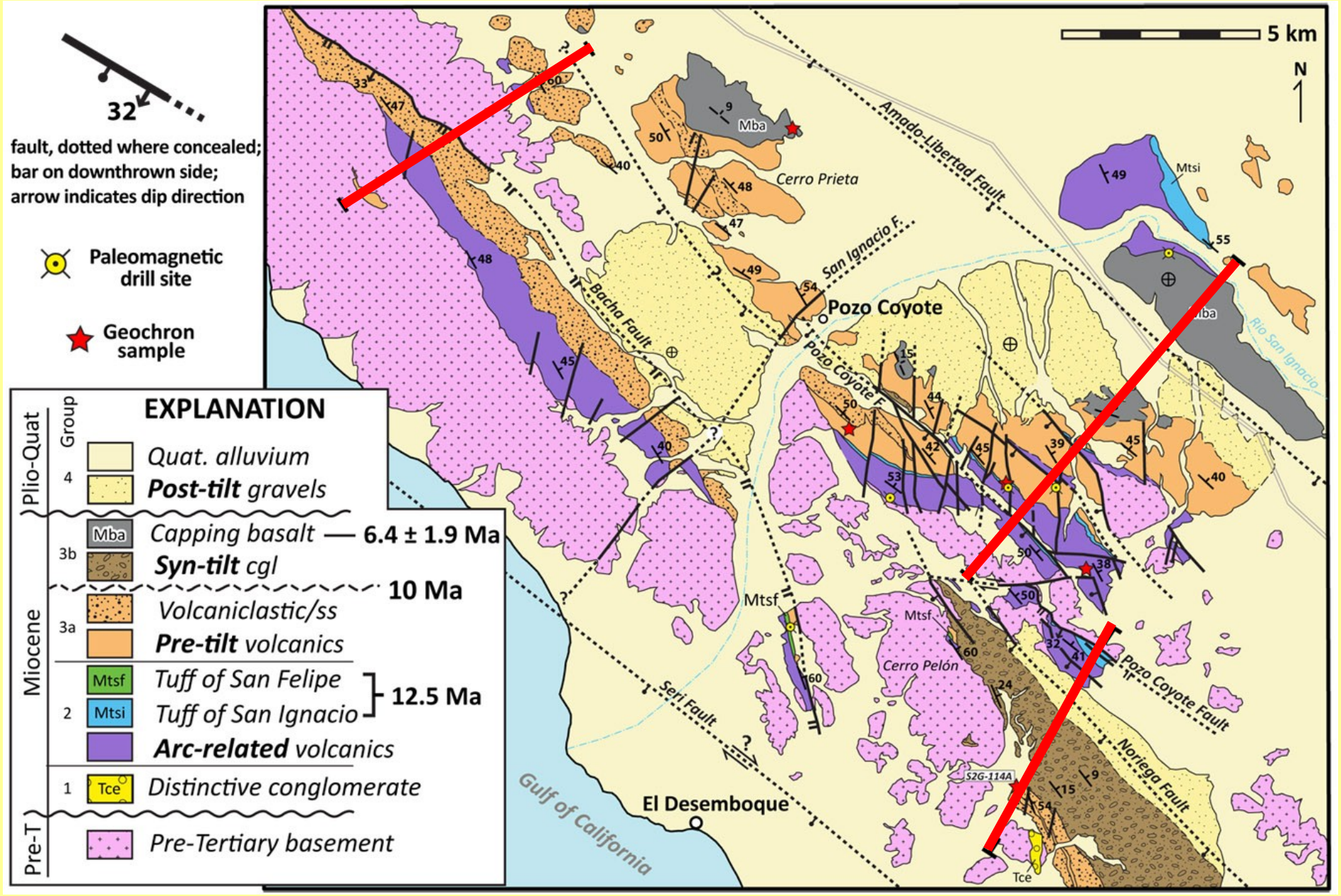
The Sierra Bacha - Stratigraphy



- 2.5 km-thick volcanic section
- Fanning dip (30-0º) in 10-6 Ma "Syn-tilt" units
- 15-10 Ma "Pre-tilt" units dip 40-60º NE

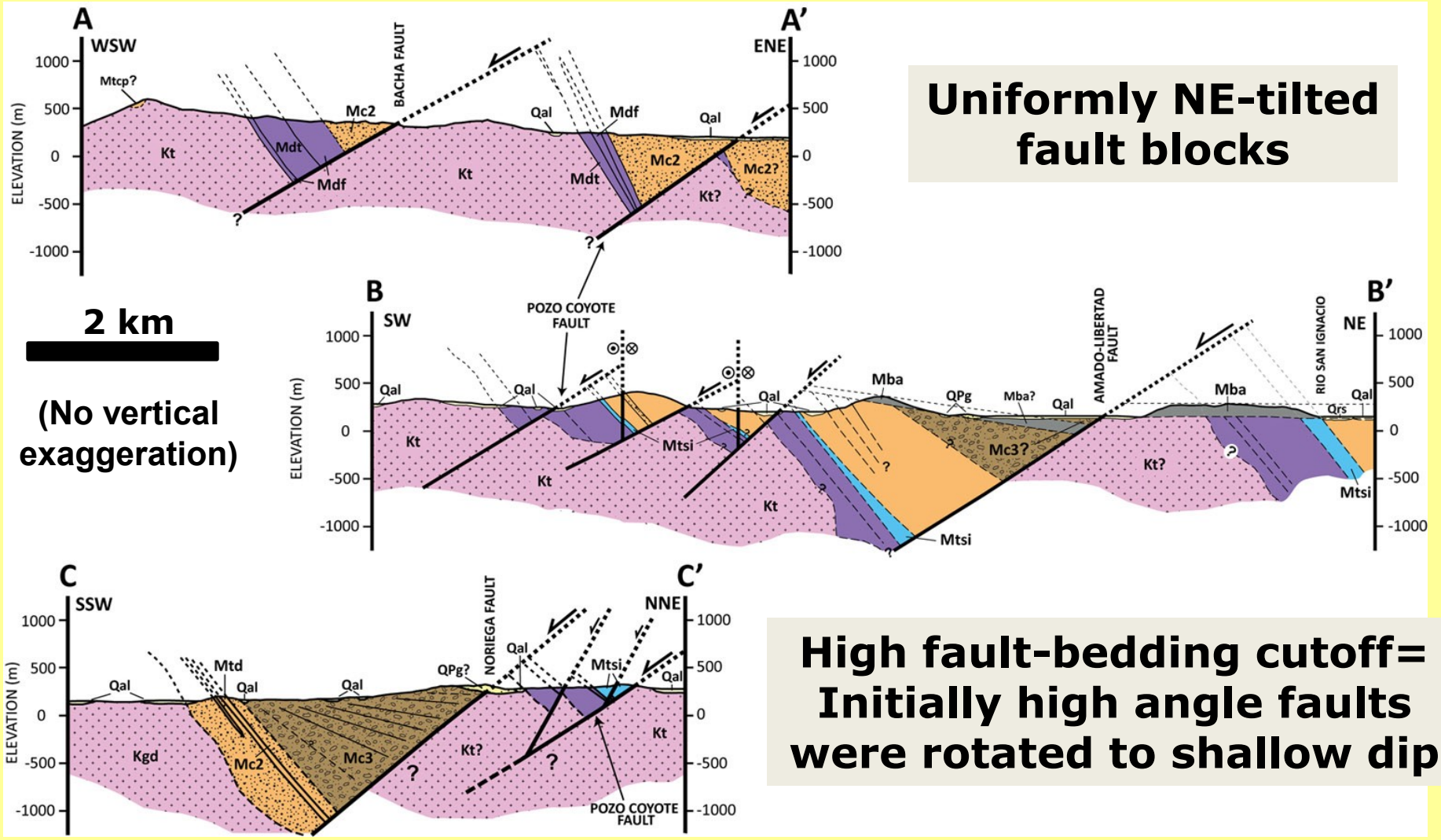


The Sierra Bacha - Structure



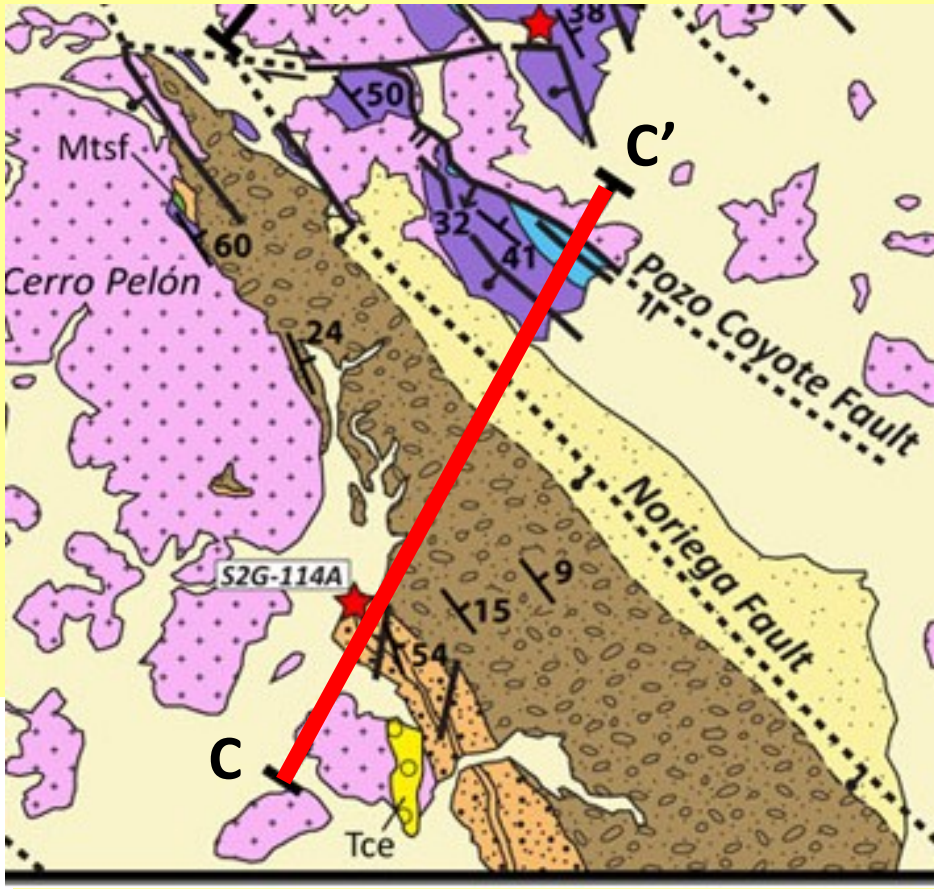
The Sierra Bacha - Structure

6 km (55-60%) EXTENSION from ~10-6 Ma



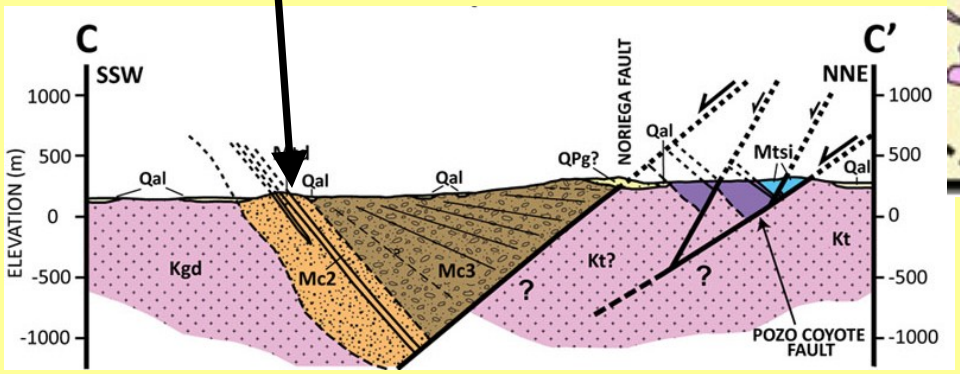
The Sierra Bacha - Structure

6 km (55-60%) EXTENSION from ~10-6 Ma



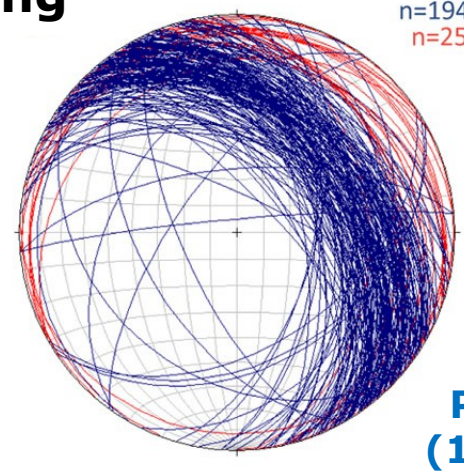
2 km

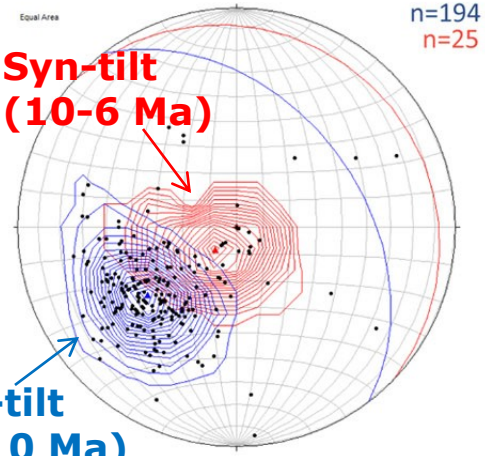
10.4 Ma tuff

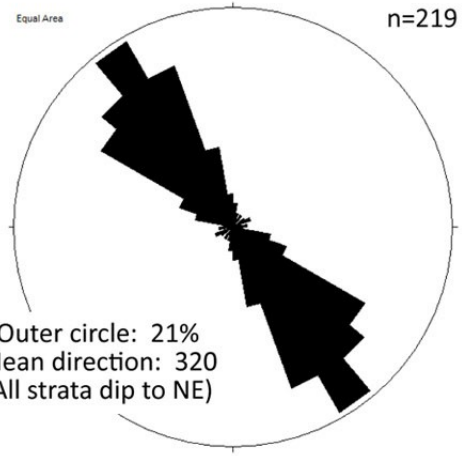


The Sierra Bacha - Structure

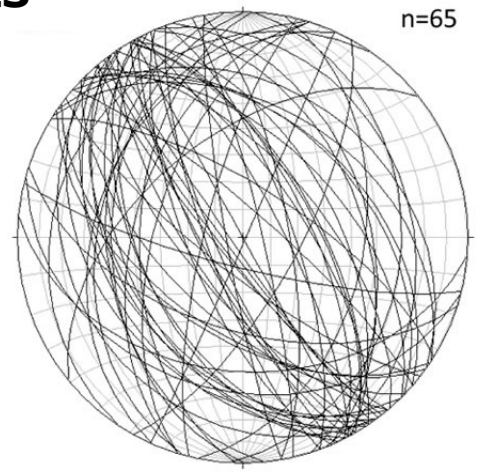
Bedding

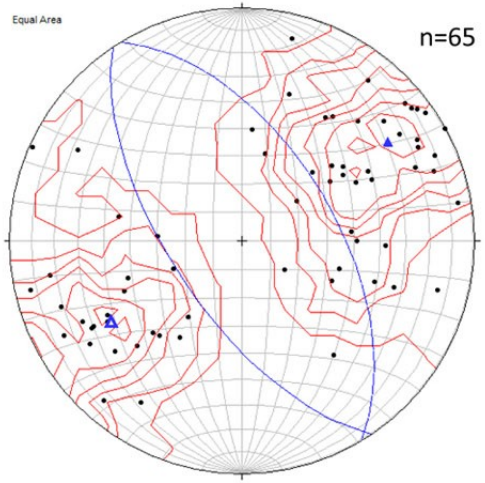


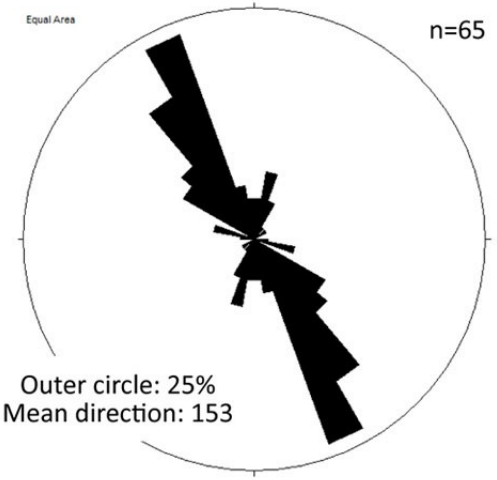




Faults



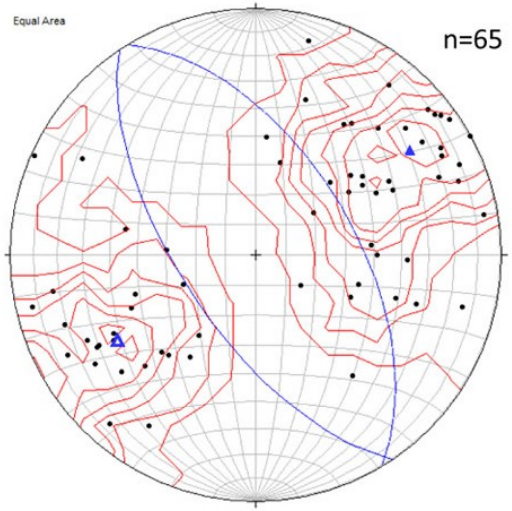




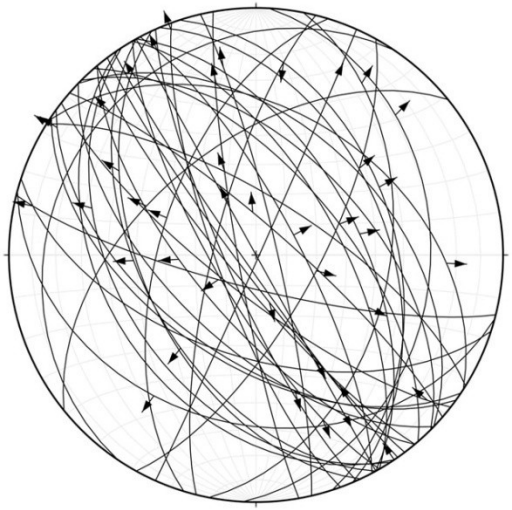
Uniformity and parallelism between bedding and faults imply orthogonal NE-SW extension

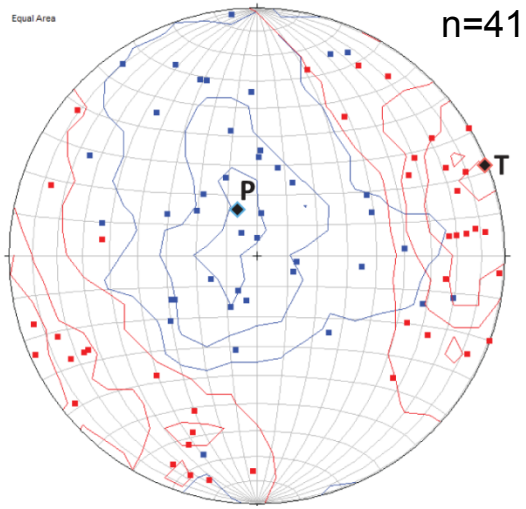
Fault Kinematic Analysis

Poles to fault planes

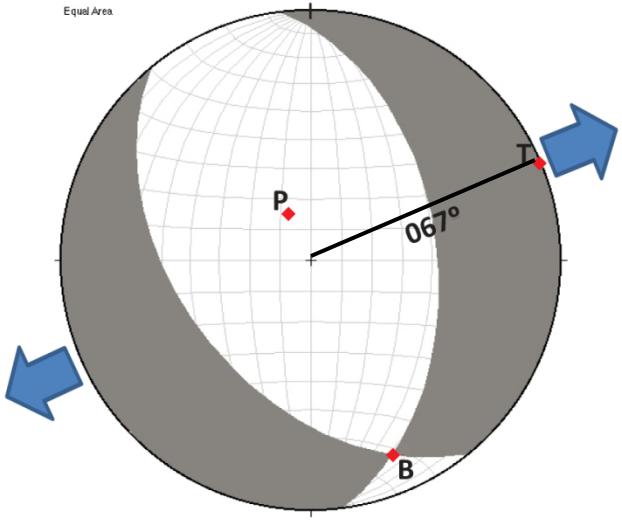


Fault planes and HW slip





Individual P & T axes



65 fault surfaces

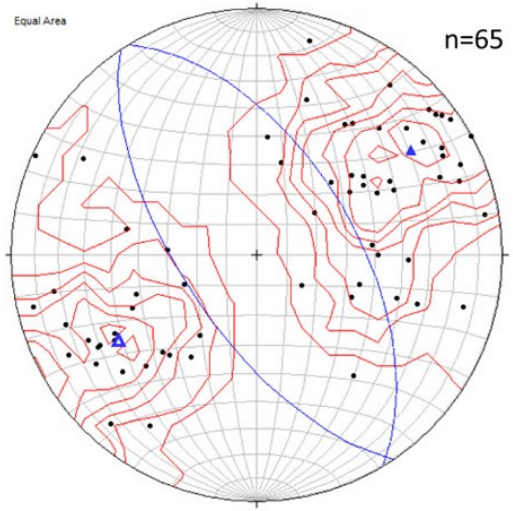
41 kinematic indicators

Compatible with ENE-WSW extension

(FaultKinWin v. 4.3.5, Allmendinger et al., 1994)

Fault Kinematic Analysis

Poles to fault planes

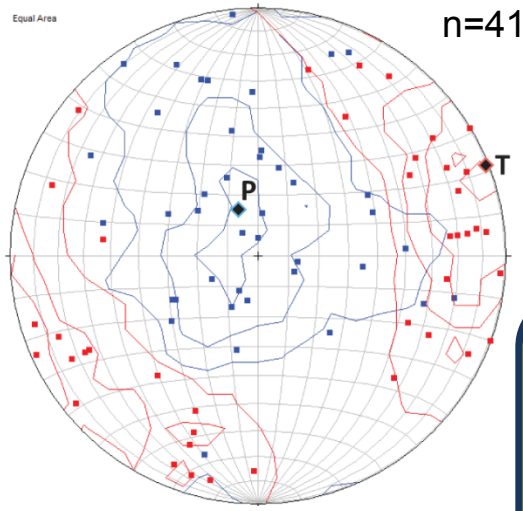


Faults cluster well and define NW-striking average conjugate fault pair

65 fault surfaces

41 kinematic indicators

Compatible with ENE-WSW extension



Individual P & T axes

Individual P & T axes show significant scatter; **unexpected for uniform fault orientation**

Oblique fault reactivation?

Complex 3-D strain?

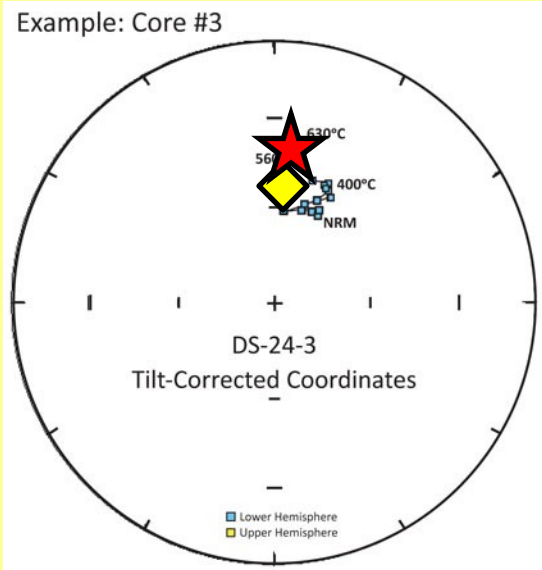
(FaultKinWin v. 4.3.5, Allmendinger et al., 1994)

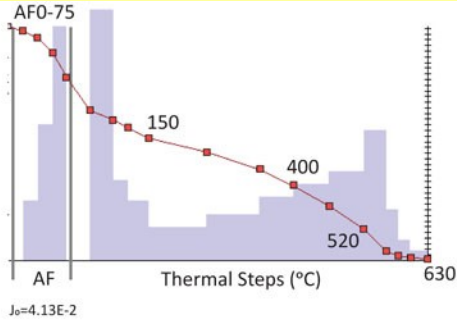
Paleomagnetism

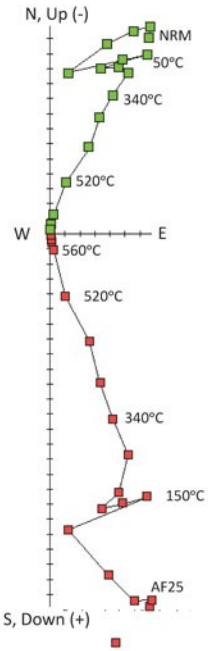
- **61 cores** from 5 units
- **AF demag** (to 80 mT)
- **Thermal demag** (to 630ºC; select samples)

★ Remanence direction

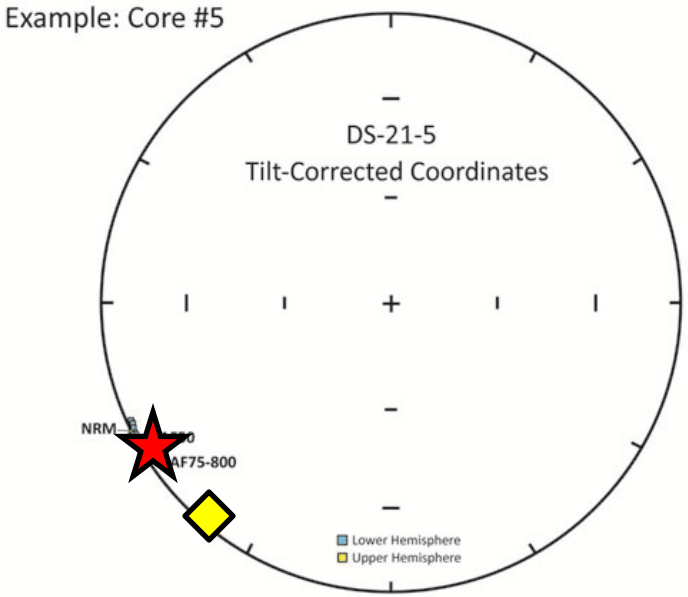
◇ Expected reference direction

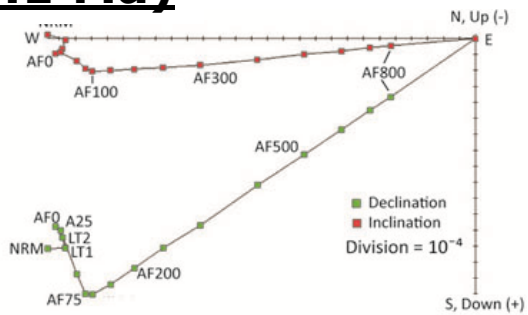


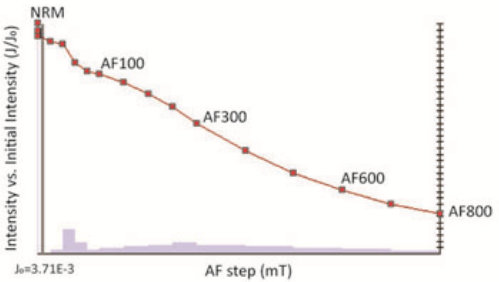


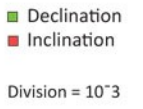


Tuff of San Felipe (12.5 ± 0.1 Ma)









6.4 ± 1.9 Ma
Capping Basalt

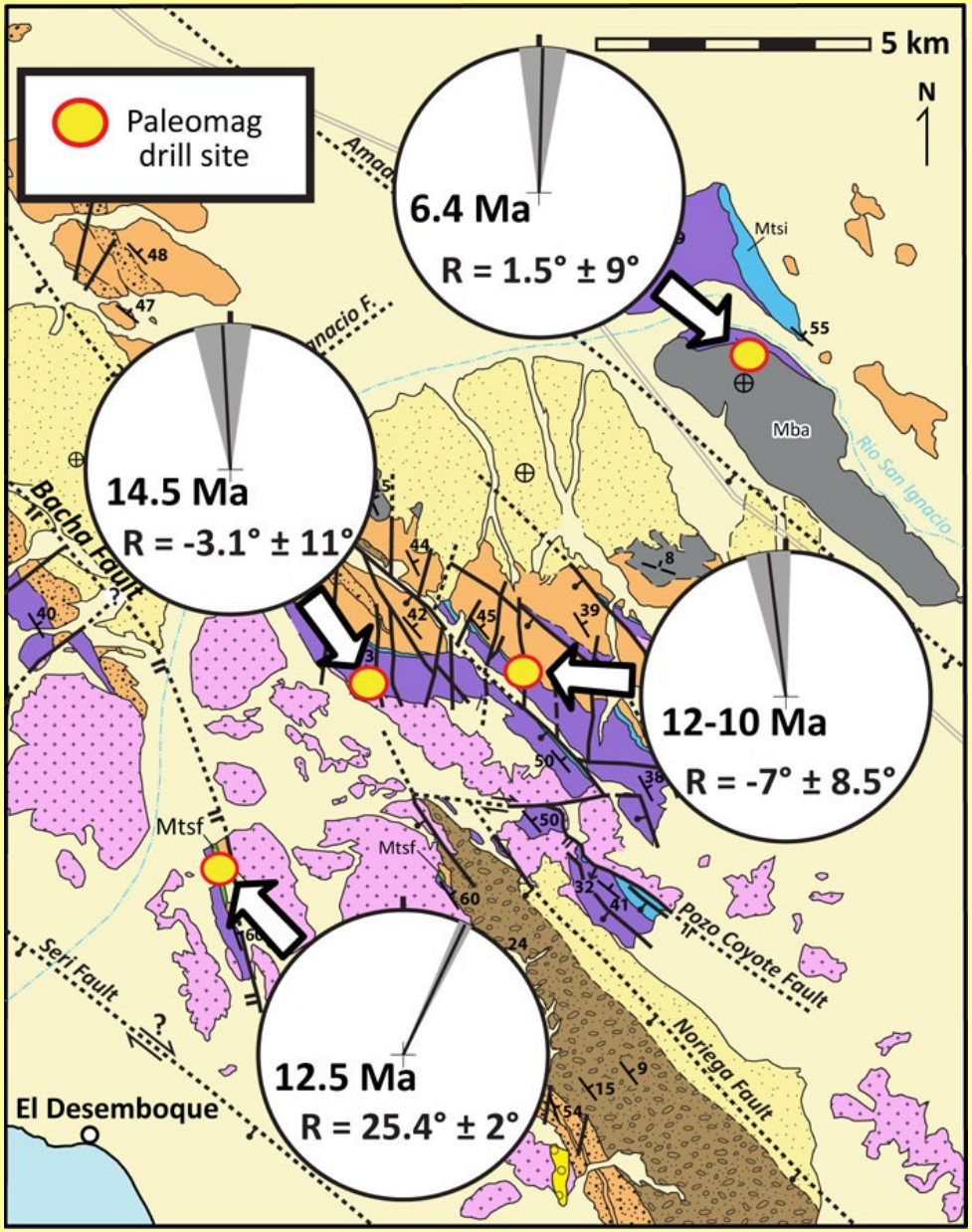
Paleomagnetism

Pilot Pmag study

-**61 cores** from 5 units
-**AF demag** (to 80 mT)
-**Thermal demag** (to 630ºC; select samples)

Results:

- Inboard sites show **no discernible rotation**
- **25º CW rotation** in SW site (post-12.5 Ma)
- Rotation related to dextral slip on Seri fault?

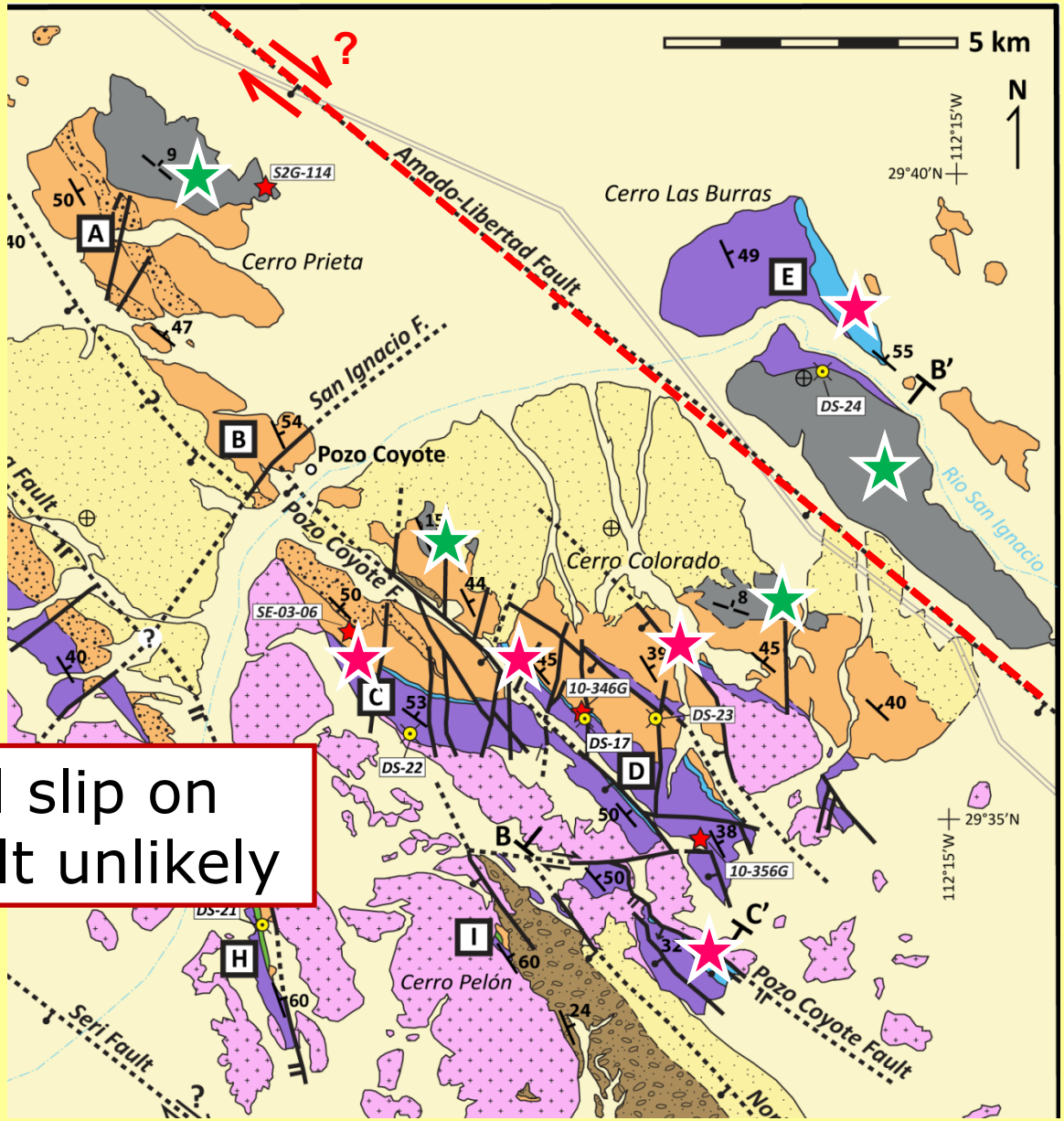


Dextral Strain – Translation??

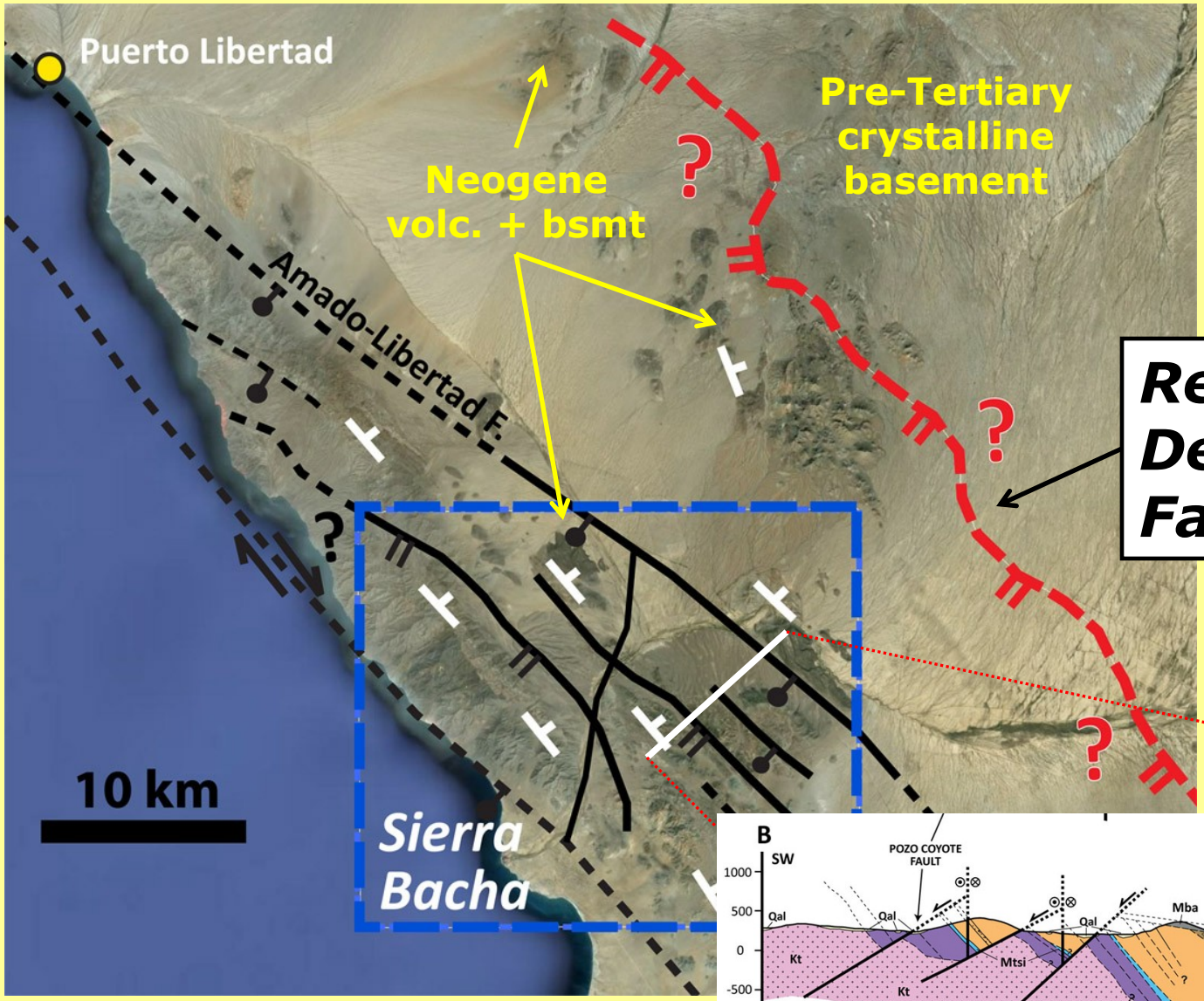
Stratigraphic evidence from geologic mapping:

- ★ Correlable 6.4 Ma basalt outcrops
- ★ Correlable 12.5 Ma tuff outcrops

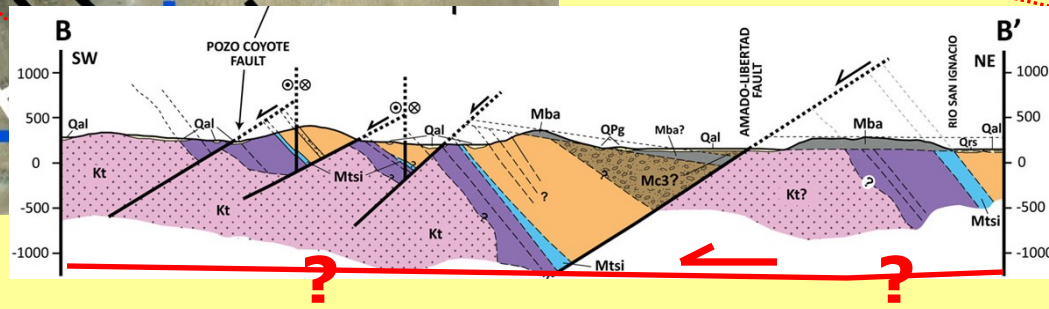
Significant dextral slip on Amado-Libertad fault unlikely



Implications for Regional Structures



Regional Detachment Fault to NE??

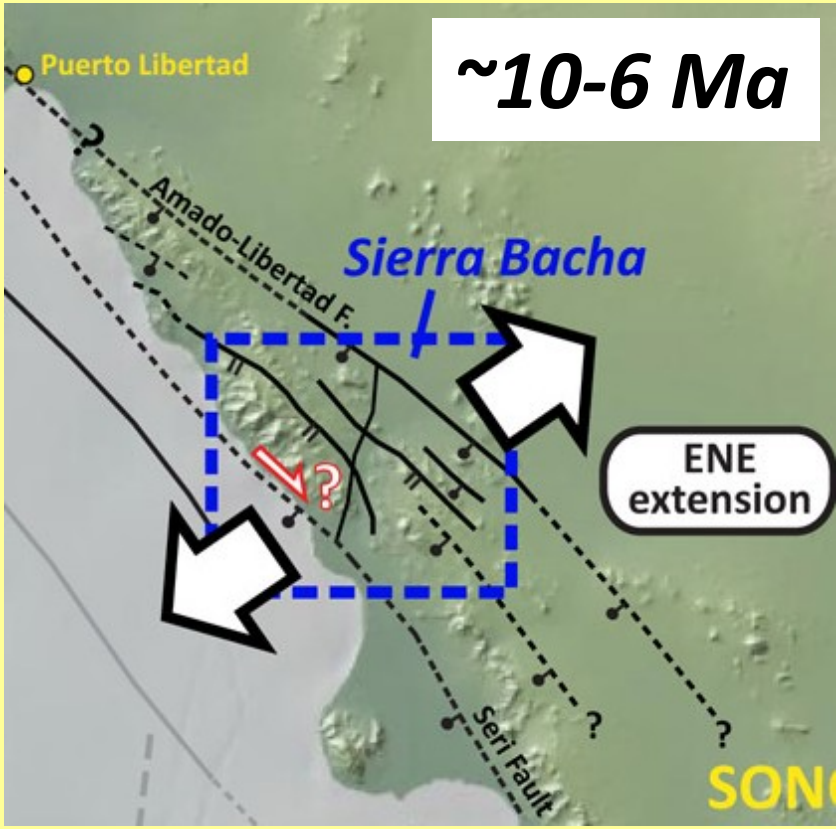


Conclusions

1) *Predominantly* ***orthogonal ENE extension*** *from 10-6 Ma*

2) ***Non-uniform paleostress*** *(oblique fault reactivation or complex 3-D strain)*

3) *Relatively* ***minor vertical-axis rotations*** *in SW Sierra Bacha*

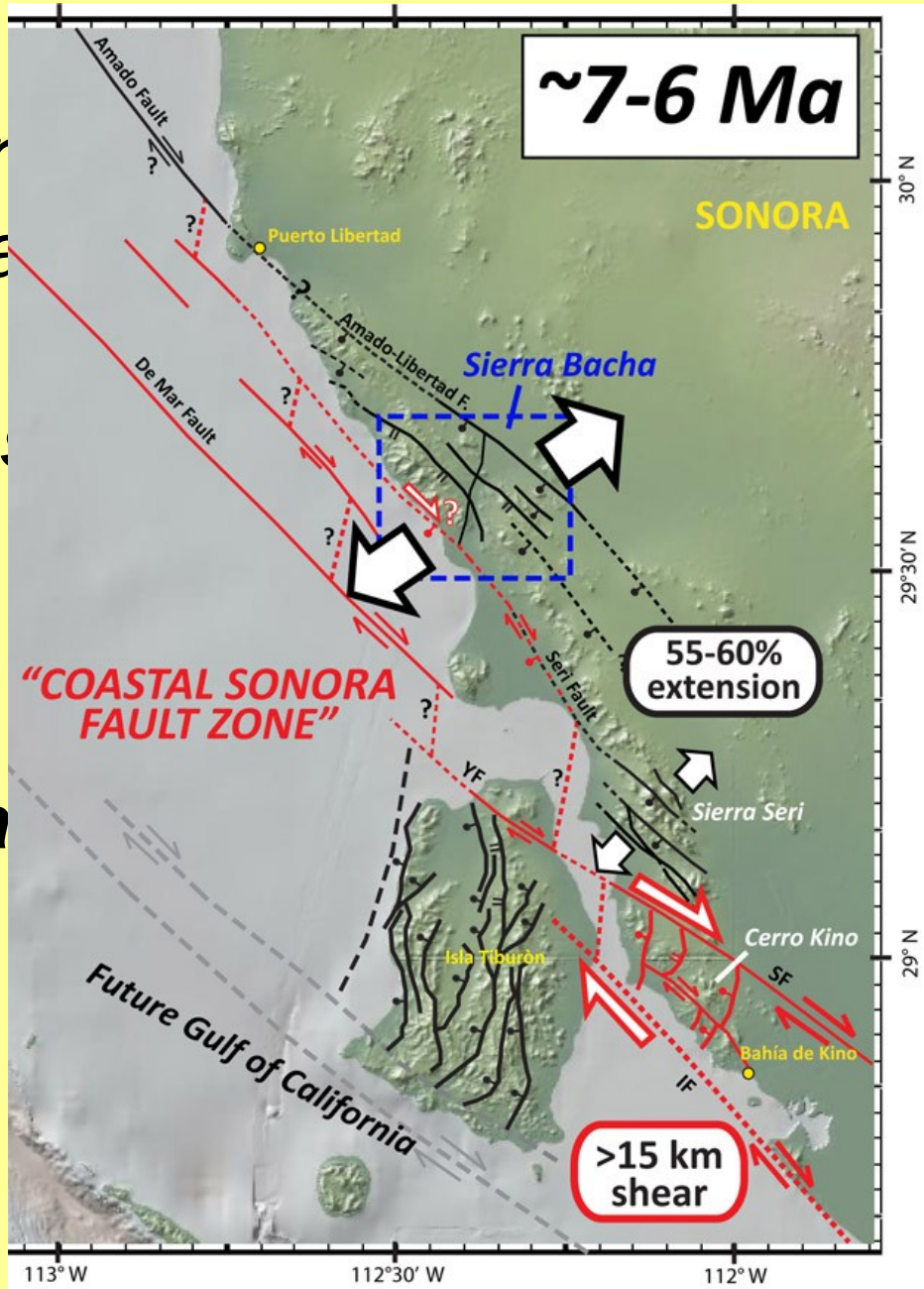


Conclusions

1) Predominantly **orthogor**
extension from 10-6 Ma

2) **Non-uniform paleostres**
(oblique fault reactivation
or complex 3-D strain)

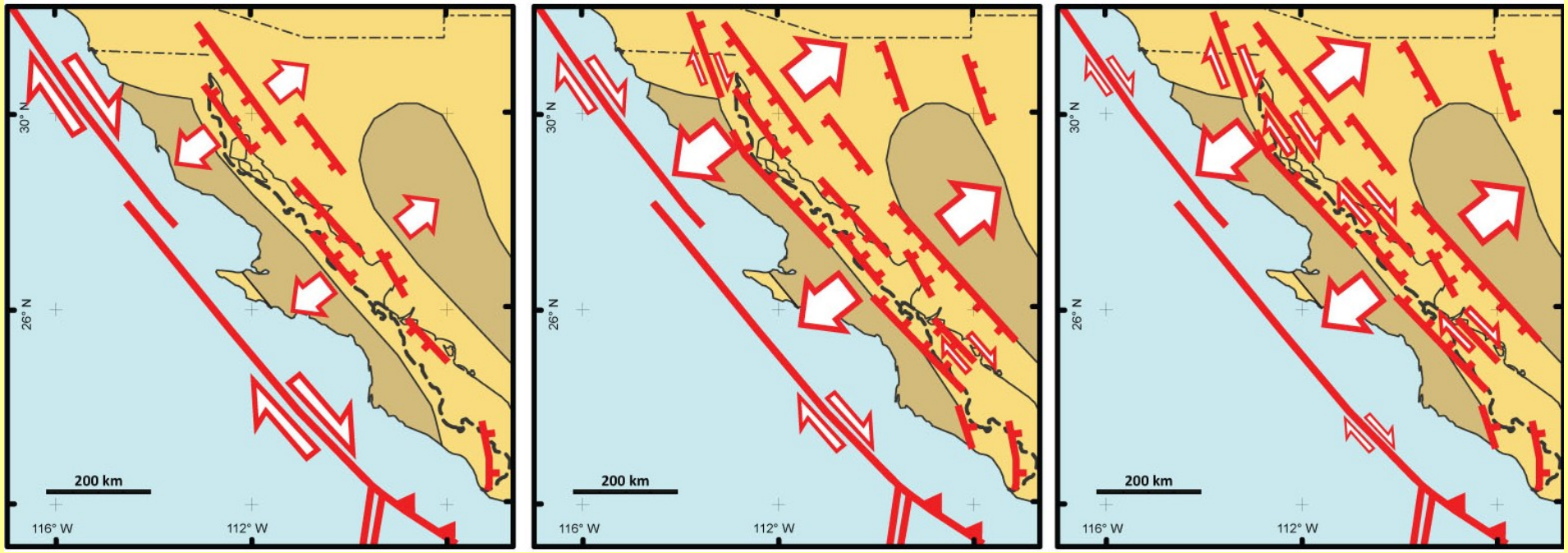
3) Relatively **minor vertica**
axis rotations in SW
Sierra Bacha



Conclusions

Intermediate model for Proto-Gulf kinematics:

12 Ma ***TIME*** ***6 Ma***



Progressive localization of dextral strain into narrow shear zones ca. 7 Ma

(Bennett, 2009; Darin, 2011; Bennett et al., in press)

Acknowledgments

- Funding from GSA, NSF
- Centro de Estudios Culturales y Ecológicos, Prescott College, Bahía de Kino
- Joann Stock, Ernesto Molina, Hector Pérez, Carl Swanson, Frank, Joe Kirschvink, Sarah Slotznick, and Steve Skinner