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Studies of Seismogenesis in Central America Utilizing Geodetic Data

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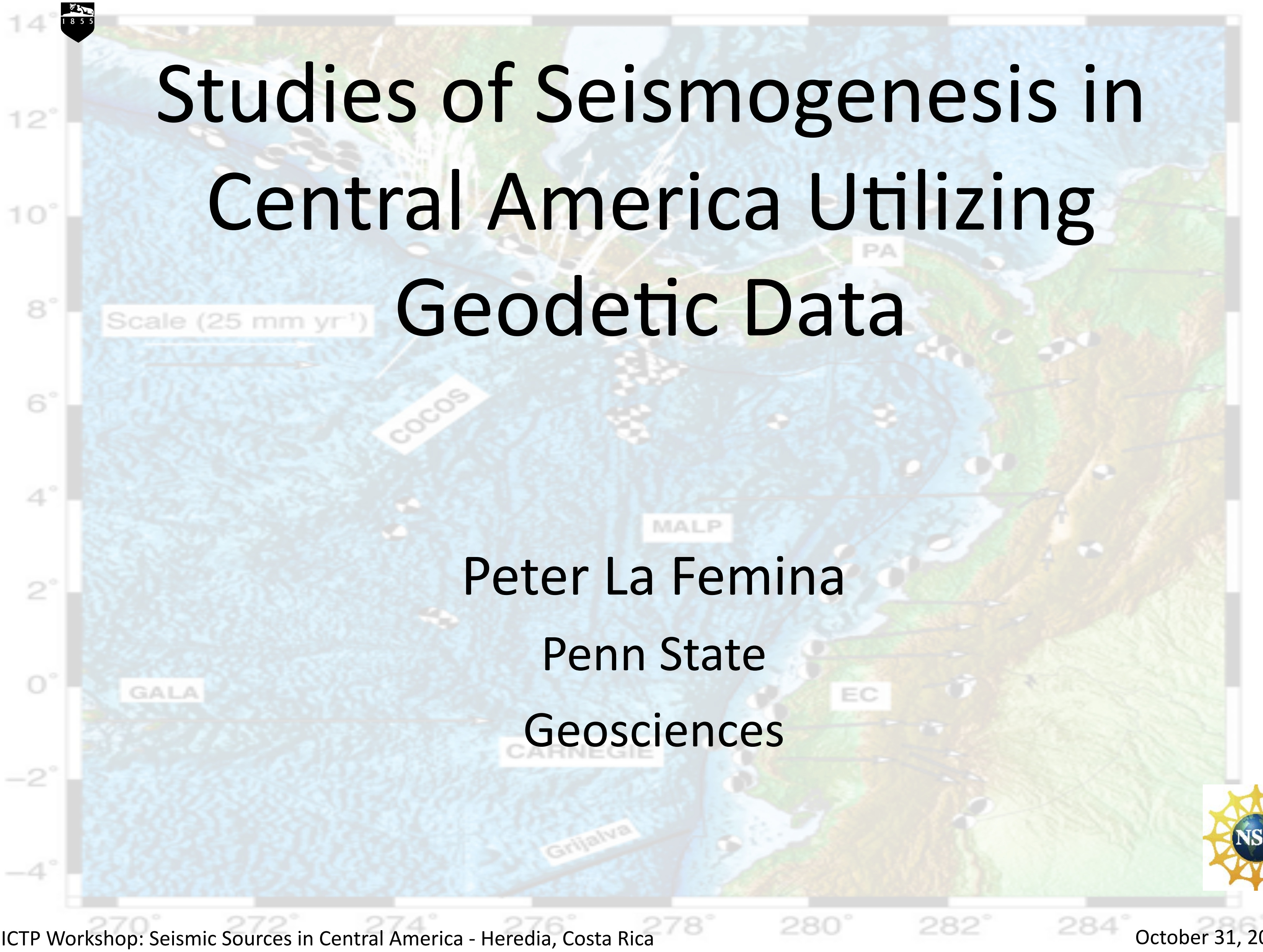
Penn State

Geosciences



Collaborators & Acknowledgements

- D. Kobayashi, H. Geirsson & D. Fisher – Penn State
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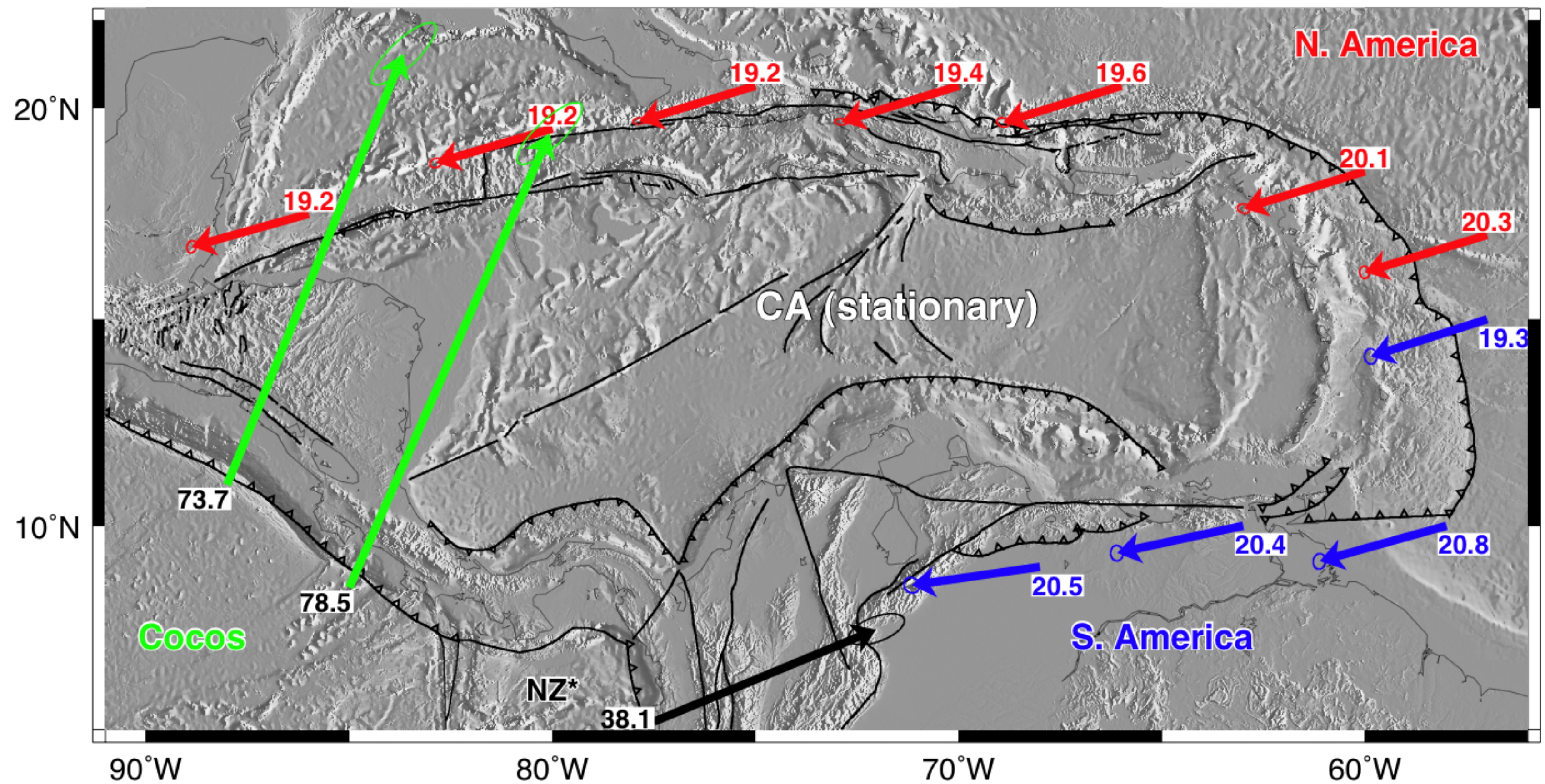
- A. Abrego - ACP
- H. Mora-Paez - INGEOMINAS
- H. Turner & G. Mattioli – Univ. Arkansas (now UT Arlington)
- C. DeMets - UWM
- NSF - EAR & MARGINS

Present Plate Motions

from MORVEL global model – DeMets et al. (2010)

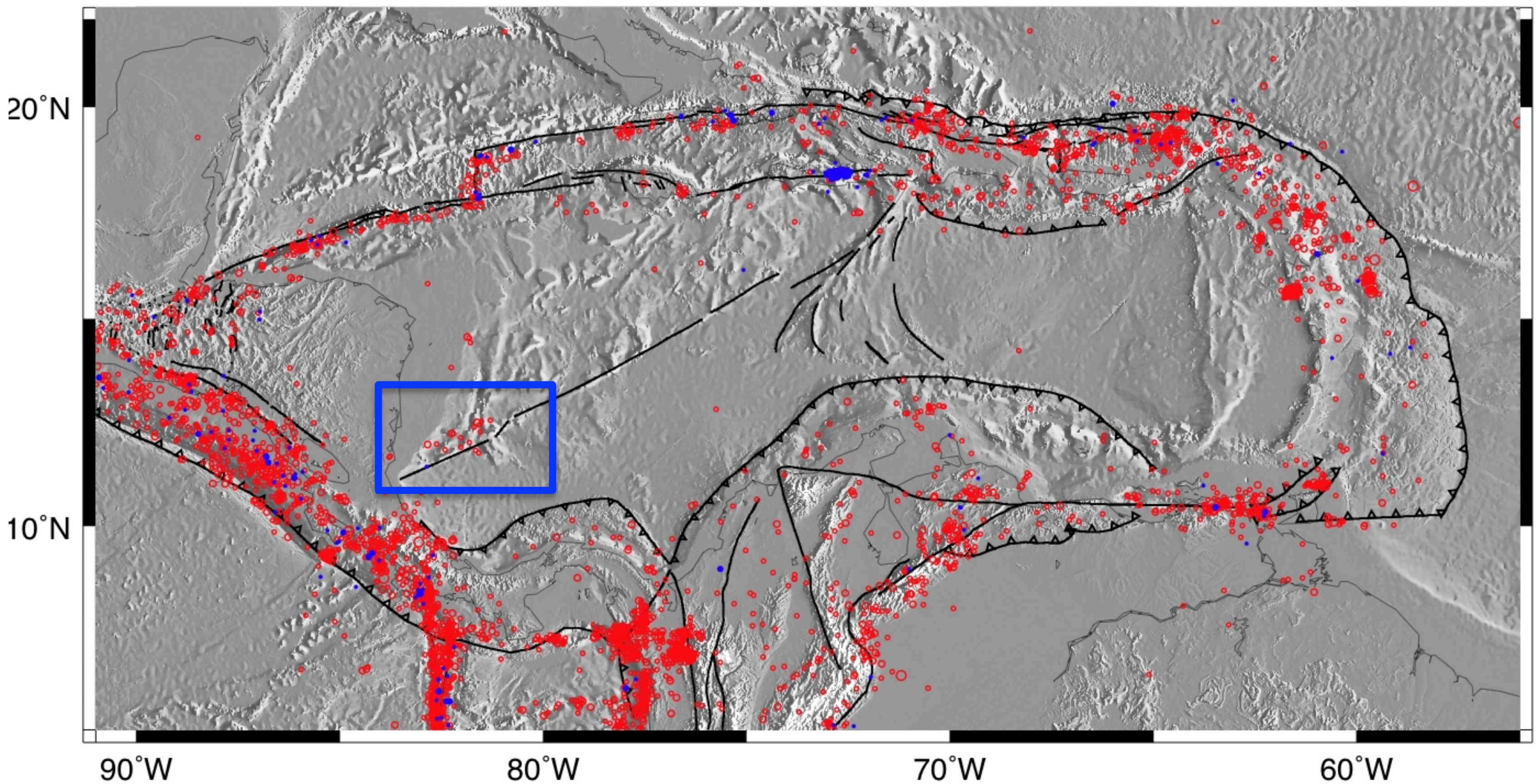
1) NA-SA convergence increases from only 1 mm/yr at east end of CA plate to 4-5 mm/yr near 75W
2) CA moves slowly (<10 mm/yr) to E or NE relative to mantle
3) Slivers at N and S edges of CA being “peeled” off interior via oblique convergence with NA and SA & sliver at W edge is migrating NW and SE symmetrical about Cocos Ridge.



1963-2011 Caribbean Seismicity

DeMets et al. (2010)

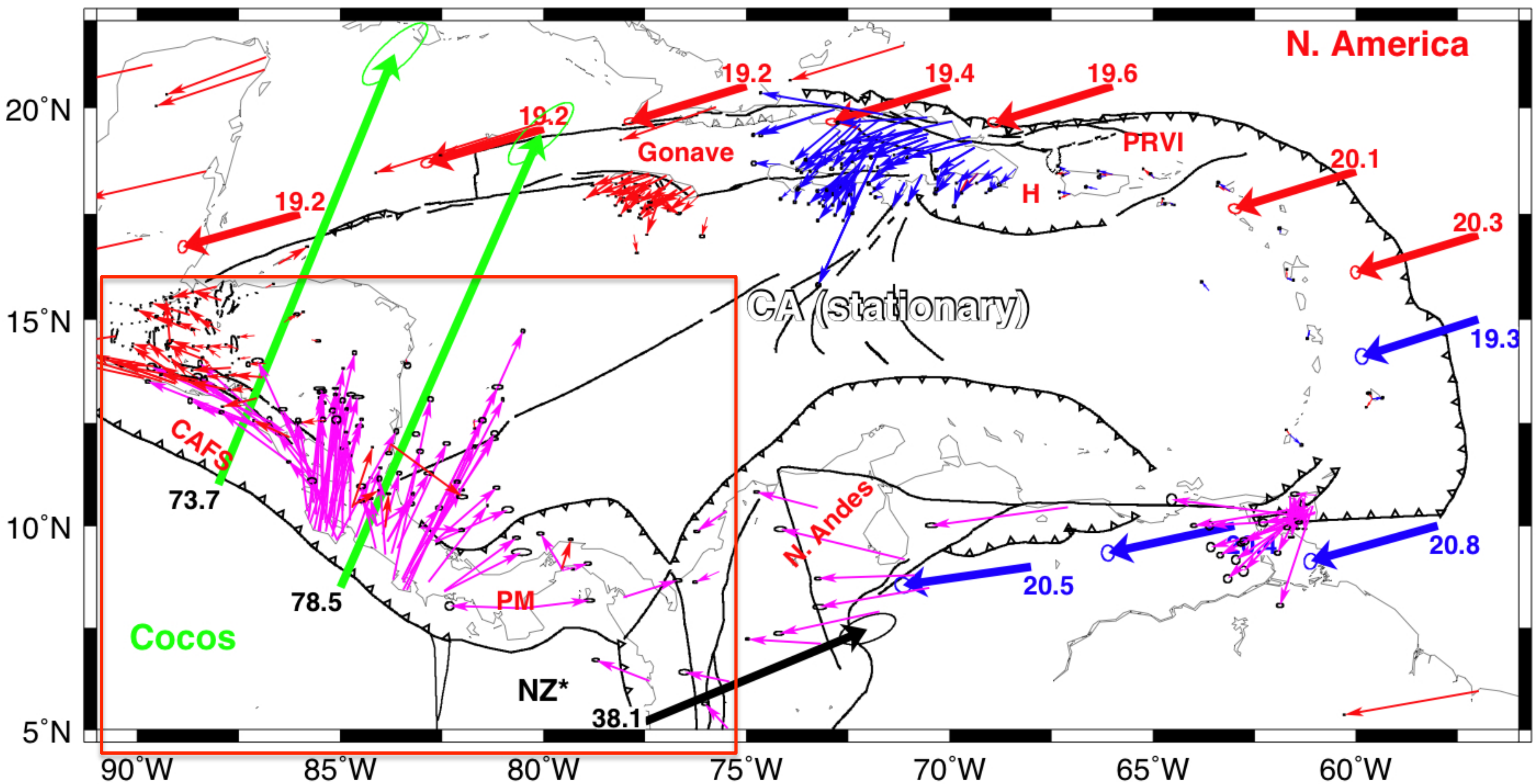
1) Plate boundaries wide everywhere except strike-slip Swan Islands fault
2) Near absence of intraplate earthquakes with one exception (see blue rectangle)
3) GPS in plate interior suggests 2 mm/yr or less for intraplate deformation (DeMets et al. 2007)



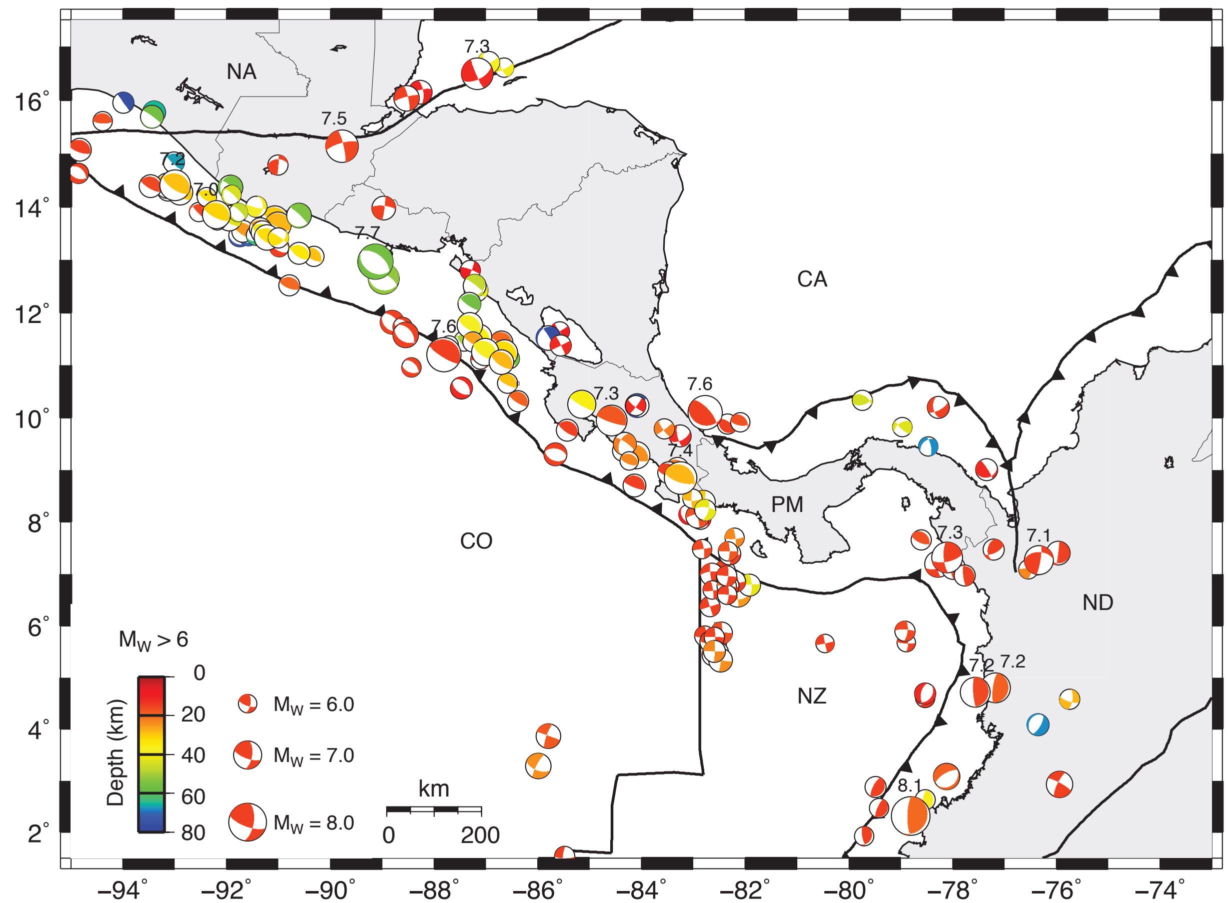
GPS Studies & Plate Motions

DeMets et al. (2010)

1) MORVEL CA plate angular velocities based on GPS due to lack of other reliable data
2) Tectonics and EQ cycle processes (interseismic fault locking & transients) from GPS comparison to plate motions



Central & N. South America Seismicity



Kobayashi et al. (2011; in preparation)

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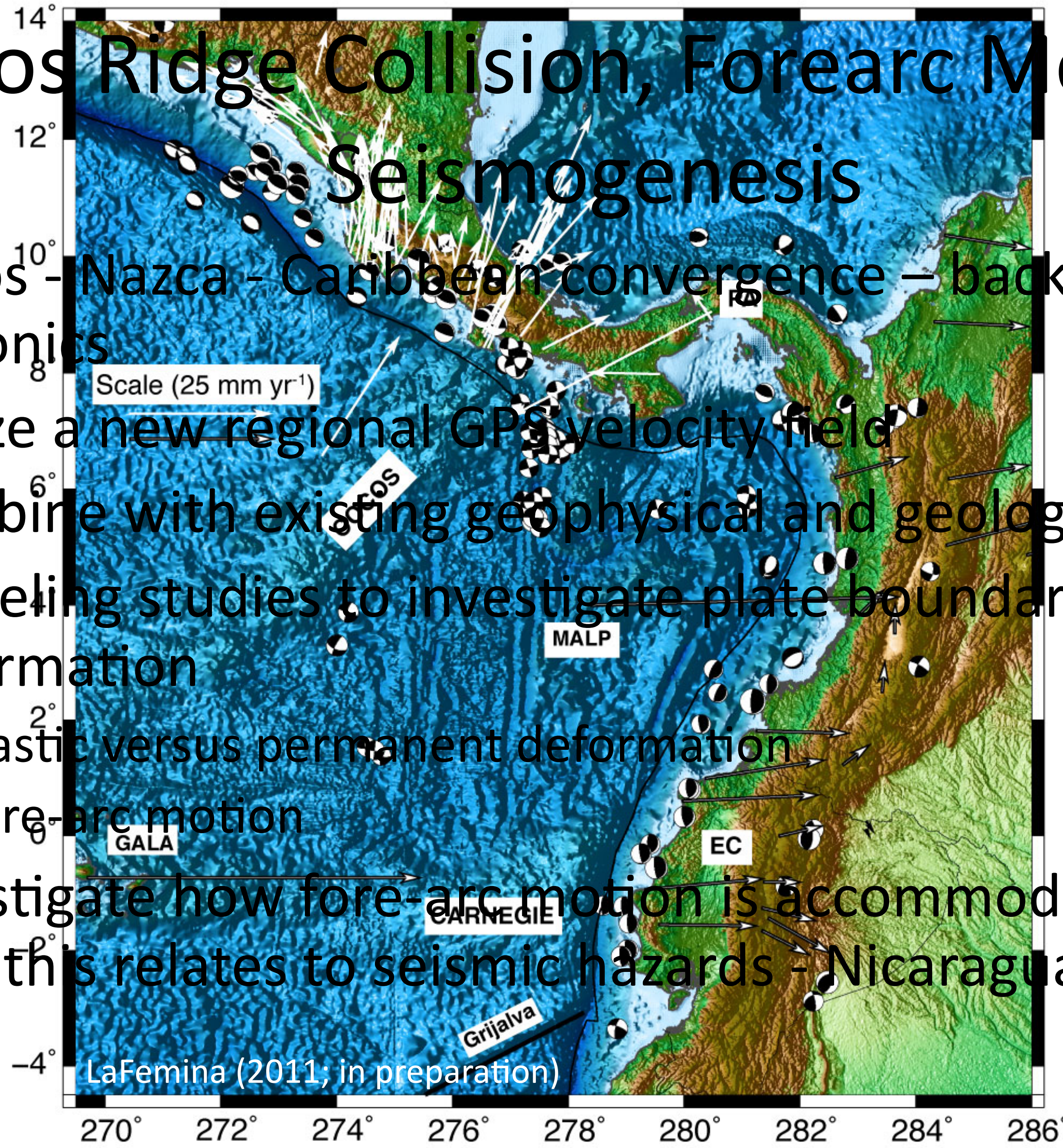
Cocos Ridge Collision, Forearc Motion & Seismogenesis

- Cocos - Nazca - Caribbean convergence – background tectonics
- Utilize a new regional GPS velocity field
- Combine with existing geophysical and geologic data
- Modeling studies to investigate plate boundary zone deformation
  - Elastic versus permanent deformation
  - Fore-arc motion
- Investigate how fore-arc motion is accommodated & how this relates to seismic hazards - Nicaragua



LaFemina (2011; in preparation)

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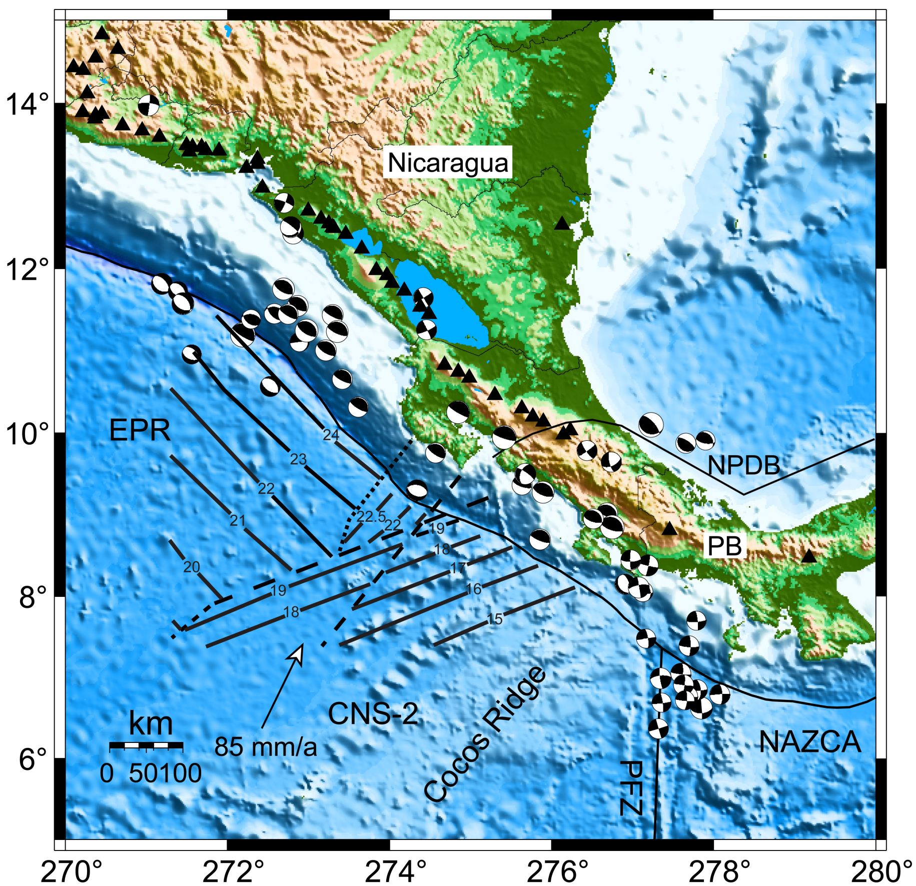
Cocos - Caribbean Interaction: Central America



LaFemina et al. (2009; G^3)

- Cocos – Caribbean convergence - 75-91 mm yr^{-1}
  - Active volcanic arc – Guatemala to central Costa Rica
- Nazca- Caribbean oblique convergence & shear - ~36 mm yr^{-1}
- Along strike changes in age & morphology (Barckhausen et al. 2001)
  - EPR-CNS-1: initiation of CNS ~23 Ma
  - CNS-1 - CNS-2: ~19 Ma; seamount domain
- CNS-2 - Cocos Ridge (13.5 - 14 Ma; ~20 km crustal thickness; Walther, 2000); since >0.5 Ma

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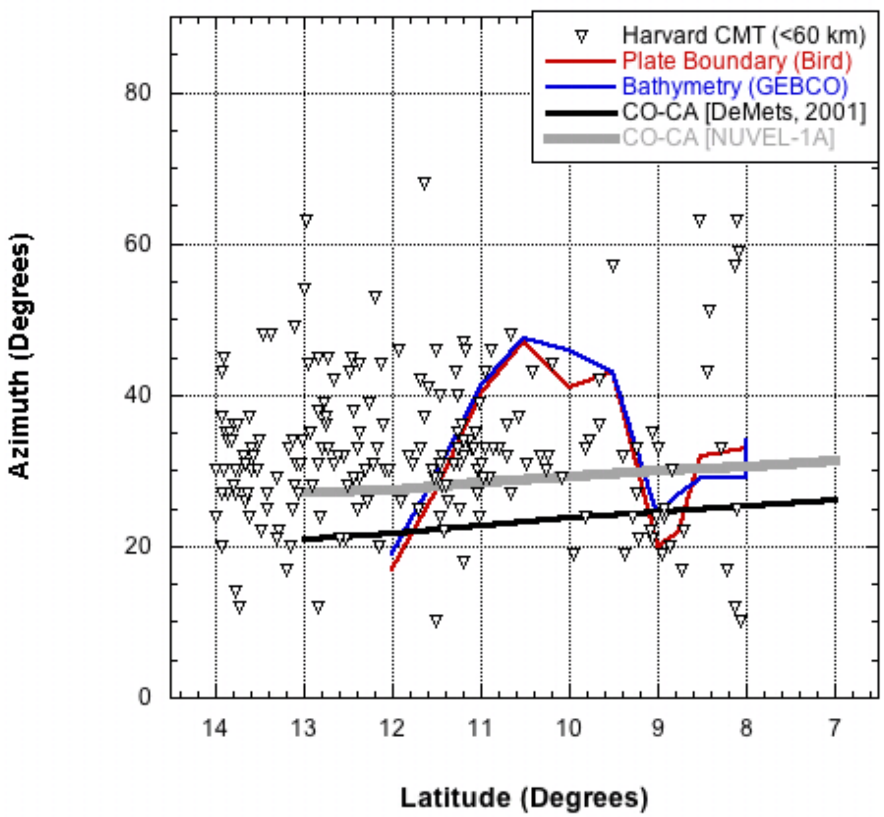
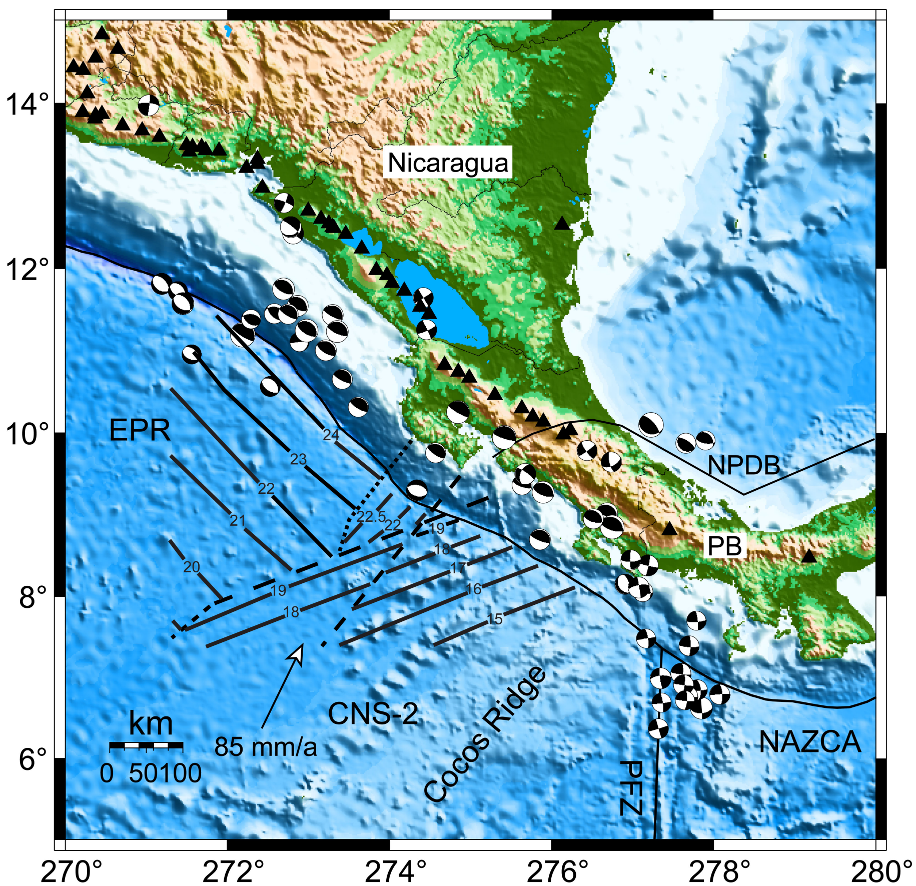
Convergence Obliquity – Strain Partitioning(?)



LaFemina et al. (2009; G^3)

- Convergence azimuth (DeMets, 2001; DeMets et al. 1994)
- EQ slip azimuth (M_w >6.0; <60 km; GCMT)
- Trench normal
- Oblique NW of C. Nicoya (>20° Nica.)
- Normal central-southern Costa Rica

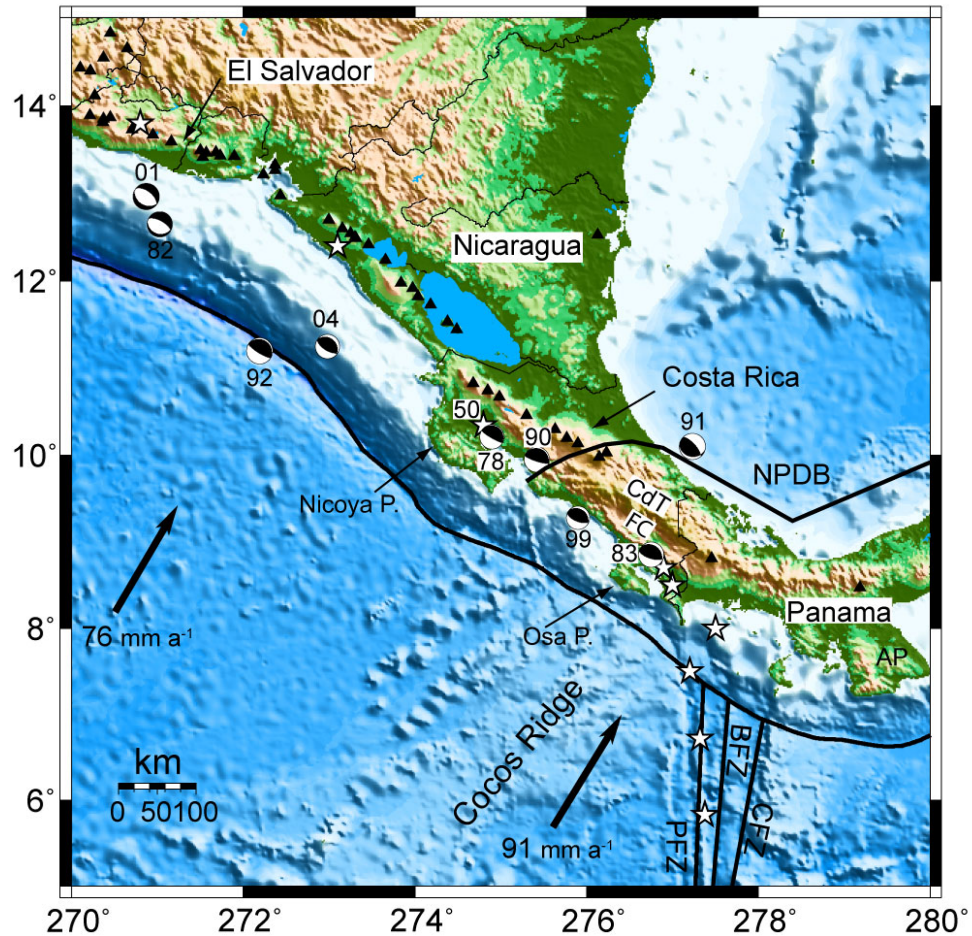
Cocos - Caribbean Interaction: Central America



LaFemina et al. (2009; G³)

- Local and global seismic tomography and relocation studies (Protti et al. 1995; DeShon et al. 2006)
  - Contortion of slab along CNS-1 - CNS-2 boundary
  - No slab inboard of CR >60 km
  - CNS-2 & Caribbean crust are under-thrusting Panama block
- Crustal shortening across Fila Costena & NPDB
- Uplift of Cordillera de Talamanca & outer fore arc
- Panama Block (?) boundaries
  - Central Costa Rica Deformed belt
  - North & South Panama Deformed belt

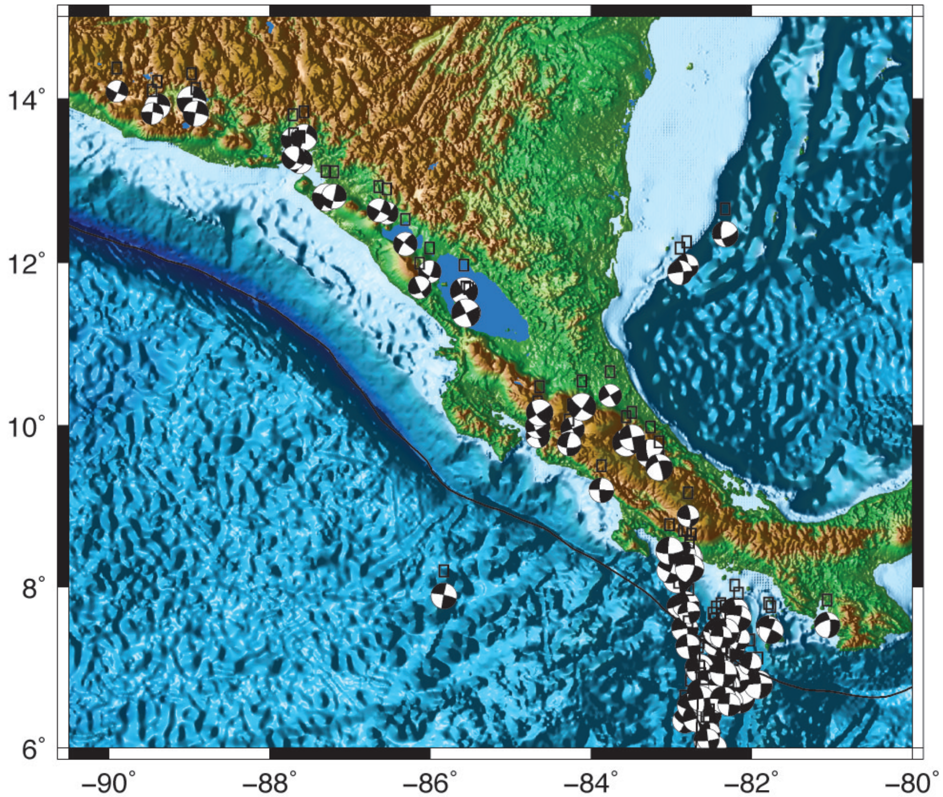
Cocos - Caribbean Interaction: Inter-Plate Seismogenesis



LaFemina et al. (2009; G^3)

- 1950 M_w 7.7 & 1990 M_w 7.3 Nicoya Peninsula
- 1983 M_w 7.4 Osa Peninsula
- 1992 M_w 7.6 Nicaraguan tsunamigenic
- 1991 M_w 7.7 El Limon/La Estrella

Cocos - Caribbean Interaction: Intra-Plate Seismogenesis



LaFemina (2011; in revision G^3)

- Upper plate seismicity indicates northwest directed fore arc sliver transport
  - Central Costa Rica to Guatemala
- Shallow (<20 km) & located within 20 km of arc
- <M 6.5
- Elongated damage zones & focal mechanisms NW to NE
- Cluster & Migrate along strike
- Historically have caused greater damage and loss of life

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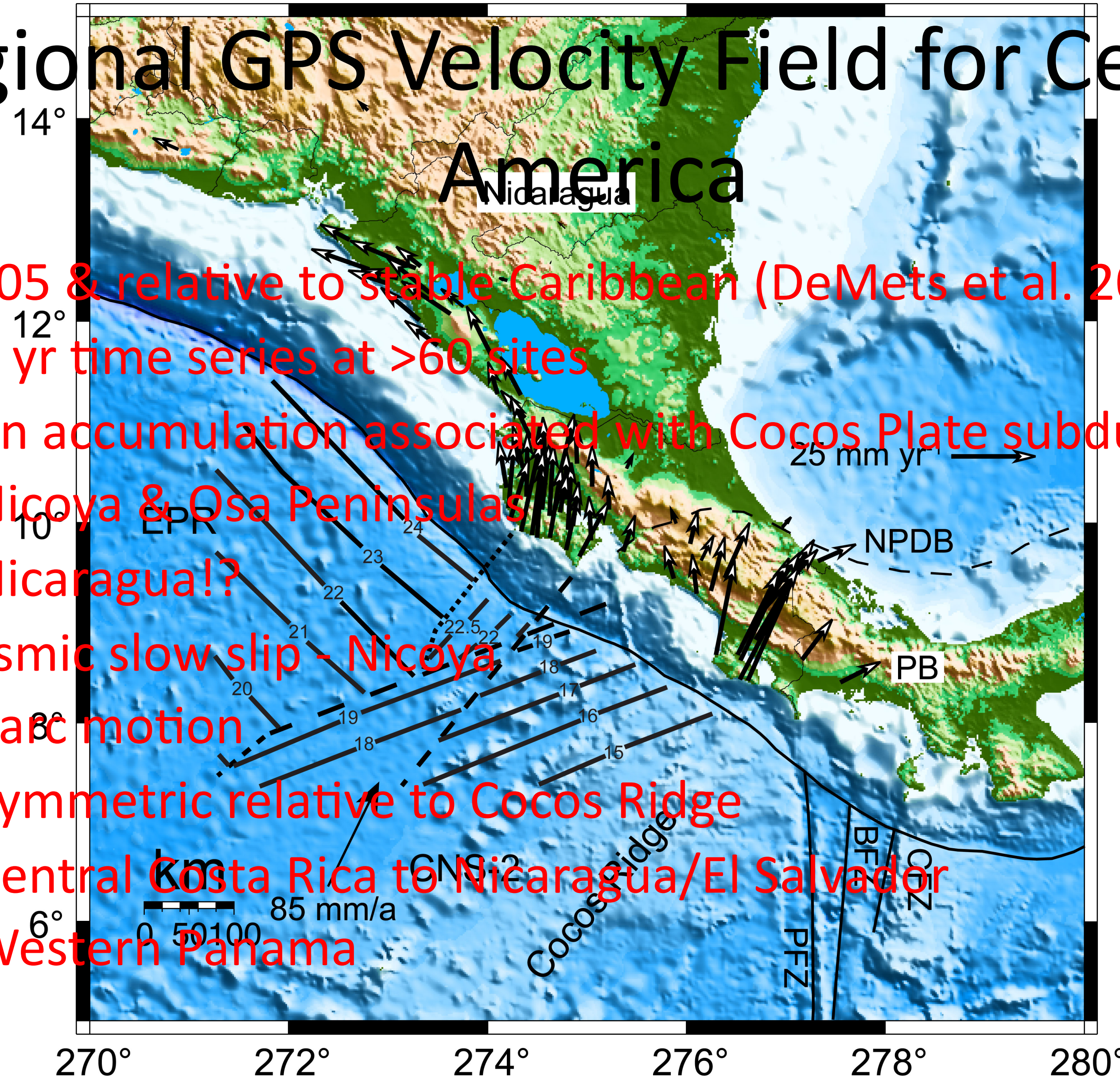
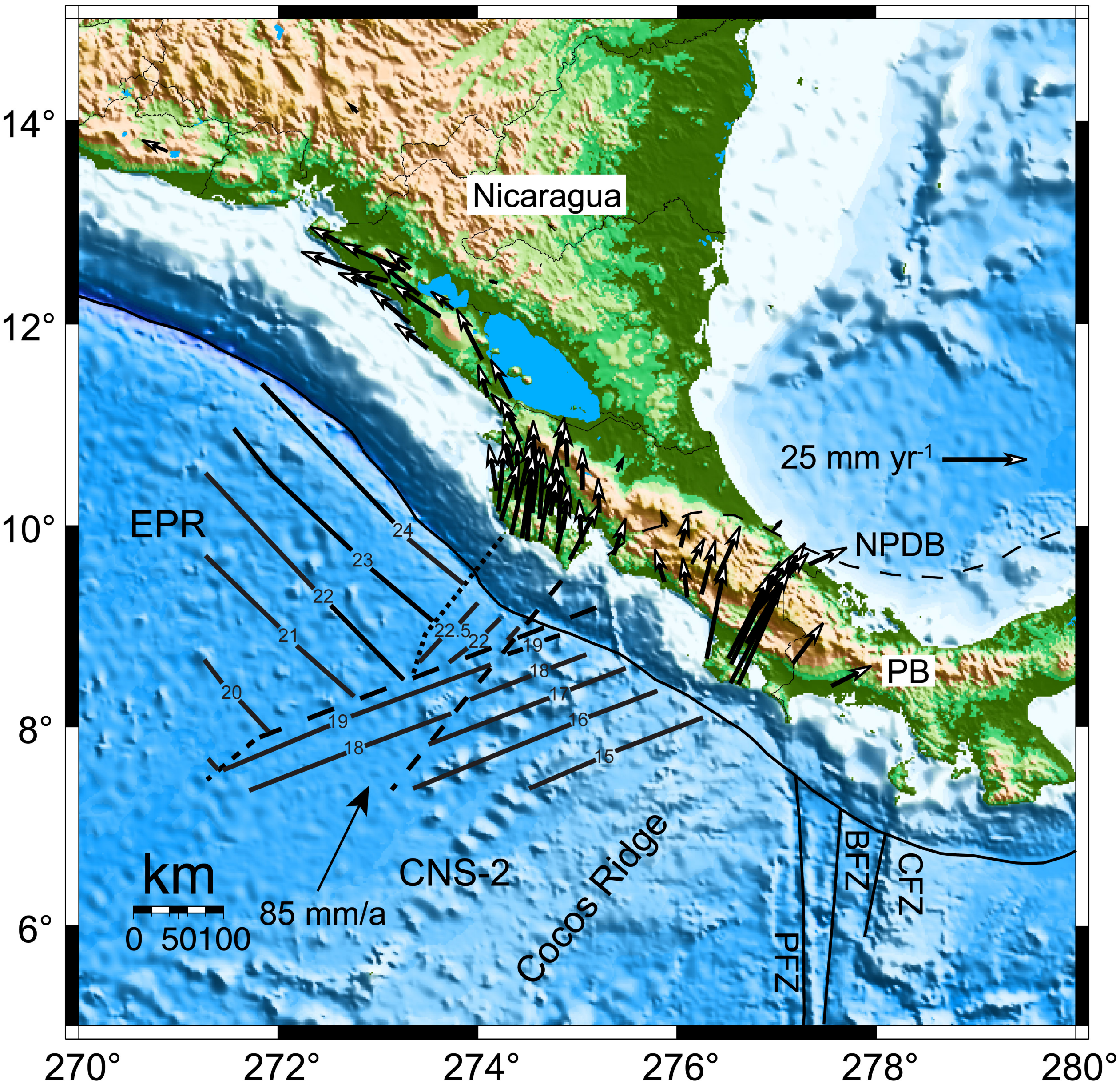
Regional GPS Velocity Field for Central America



- ITRF05 & relative to stable Caribbean (DeMets et al. 2010)
- 3-15 yr time series at >60 sites
- Strain accumulation associated with Cocos Plate subduction
  - Nicoya & Osa Peninsulas
  - Nicaragua!?
- Aseismic slow slip - Nicoya
- Forearc motion
  - Symmetric relative to Cocos Ridge
  - Central Costa Rica to Nicaragua/El Salvador
  - Western Panama

LaFemina et al. (2009; G^3)



LaFemina et al. (2009; G³)

GPS in Central America

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GPS in Central America

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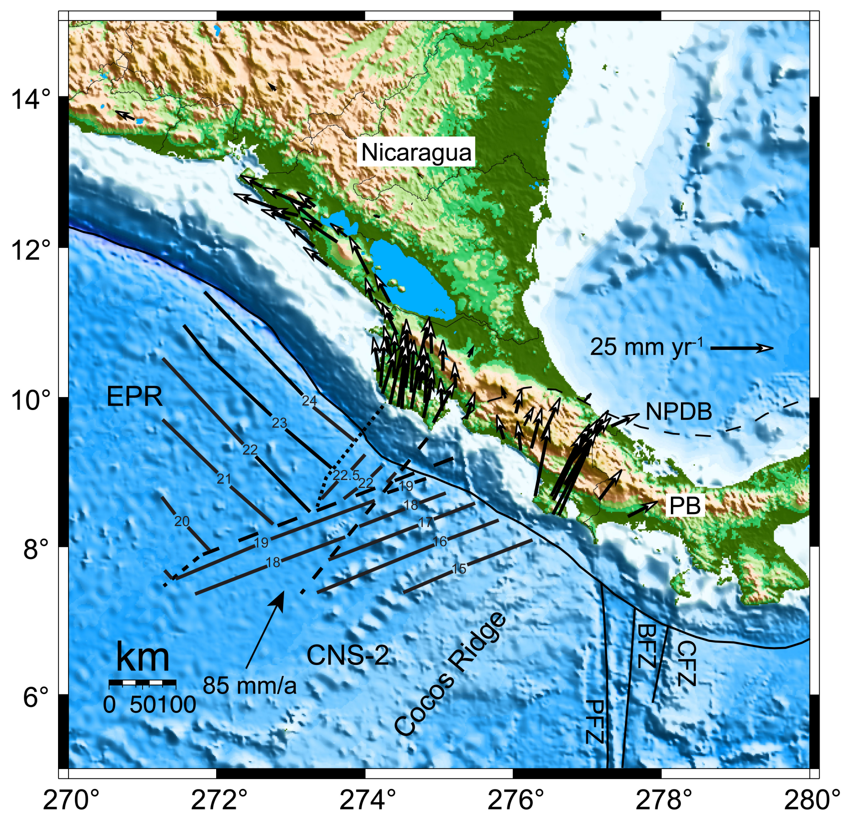
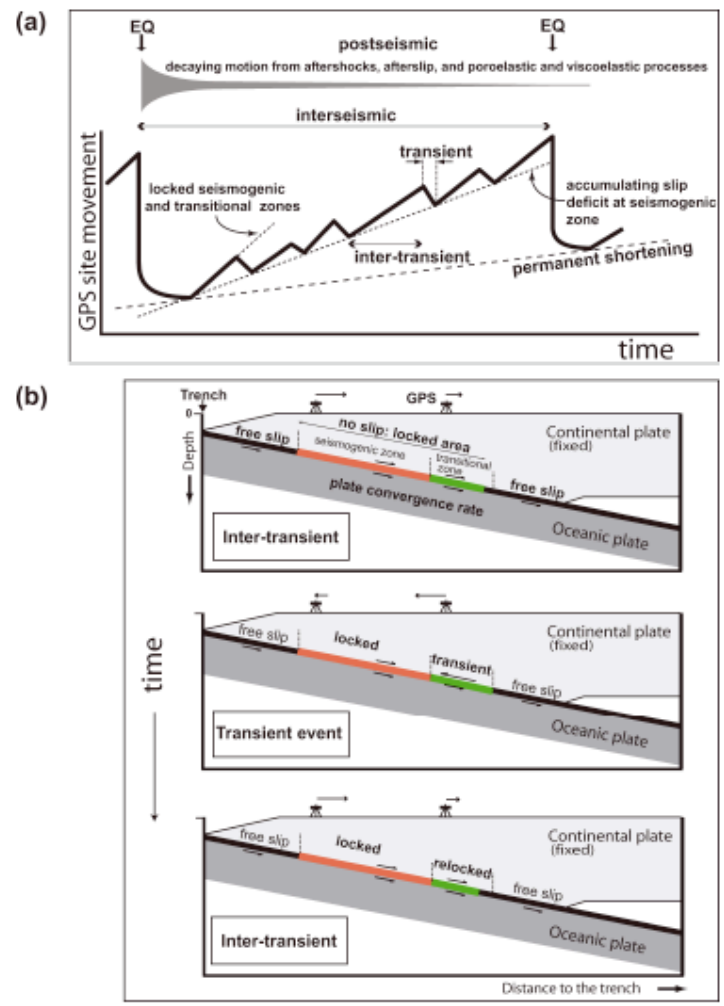
Earthquake Cycle & GPS Geodesy



LaFemina et al. (2009; G^3)



DeMets (personal comm. 2011)

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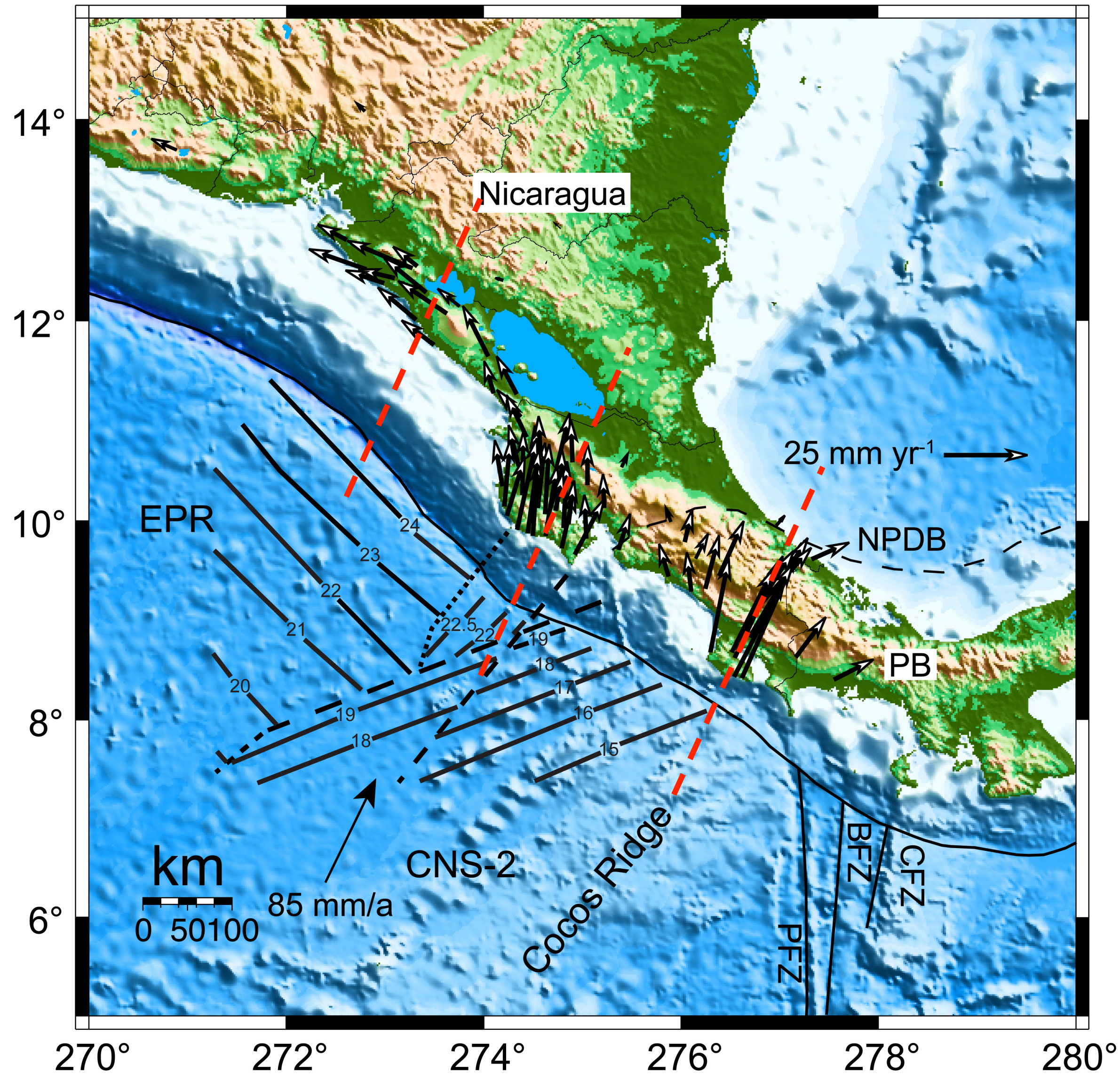

LaFemina et al. (2009; G³)

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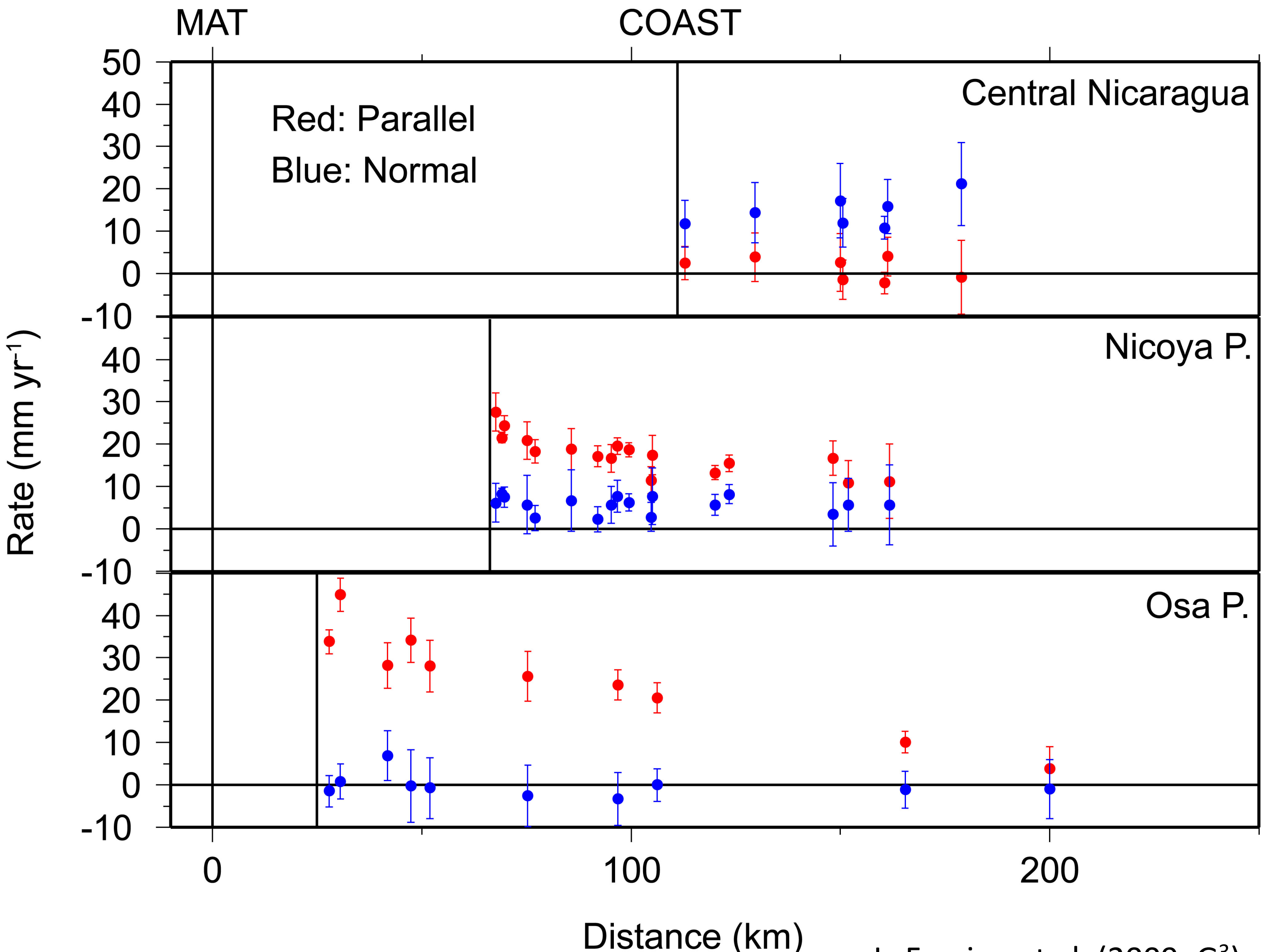
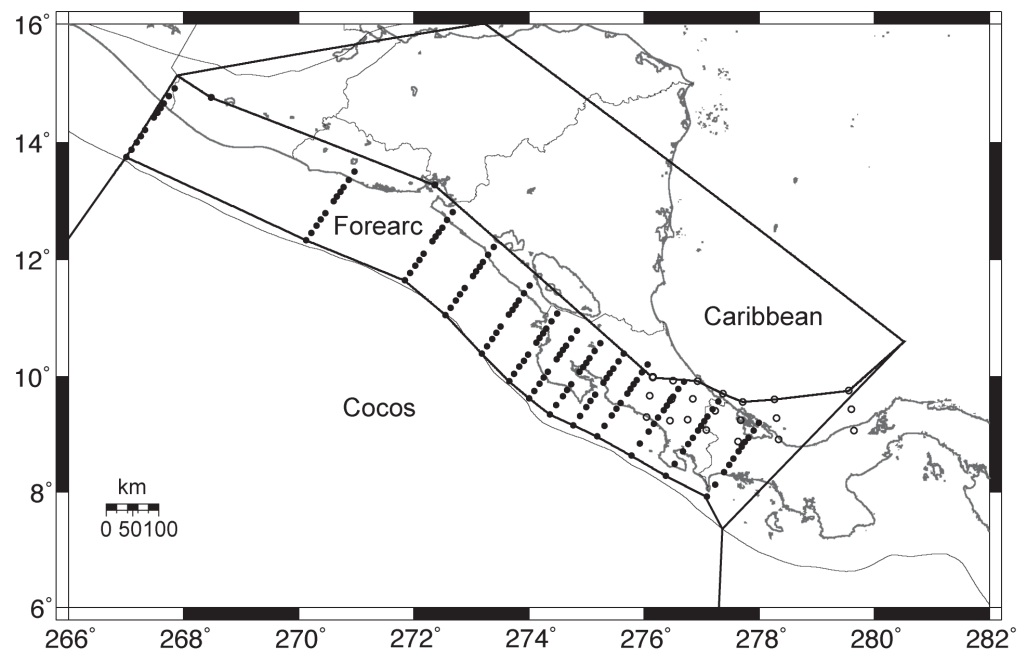


LaFemina et al. (2009; G^3)

Elastic Block Modeling

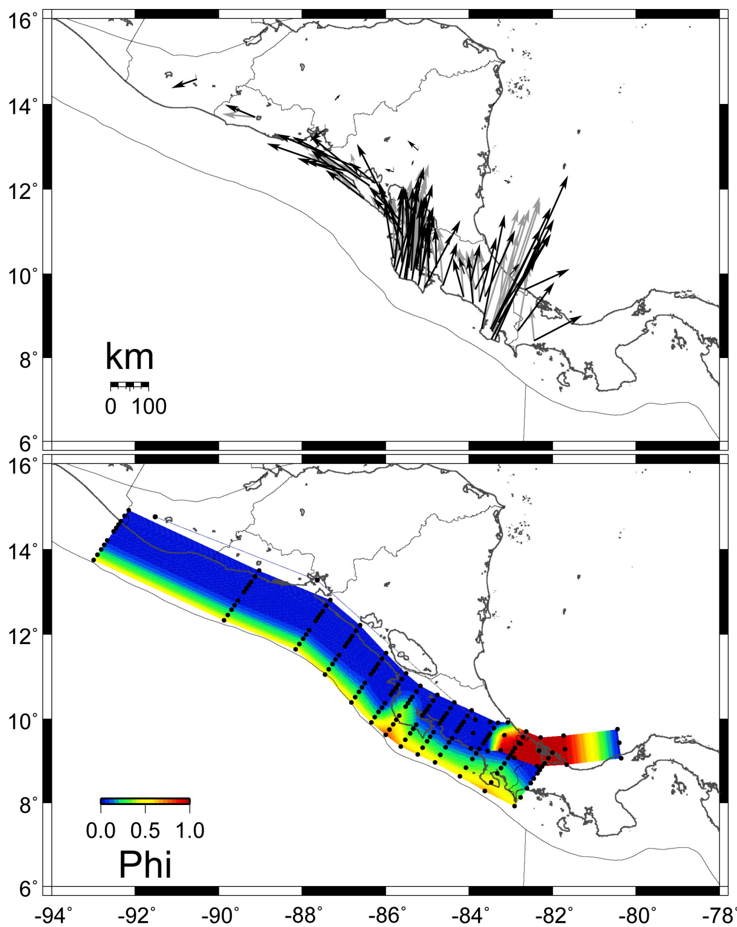


LaFemina et al. (2009; G^3)

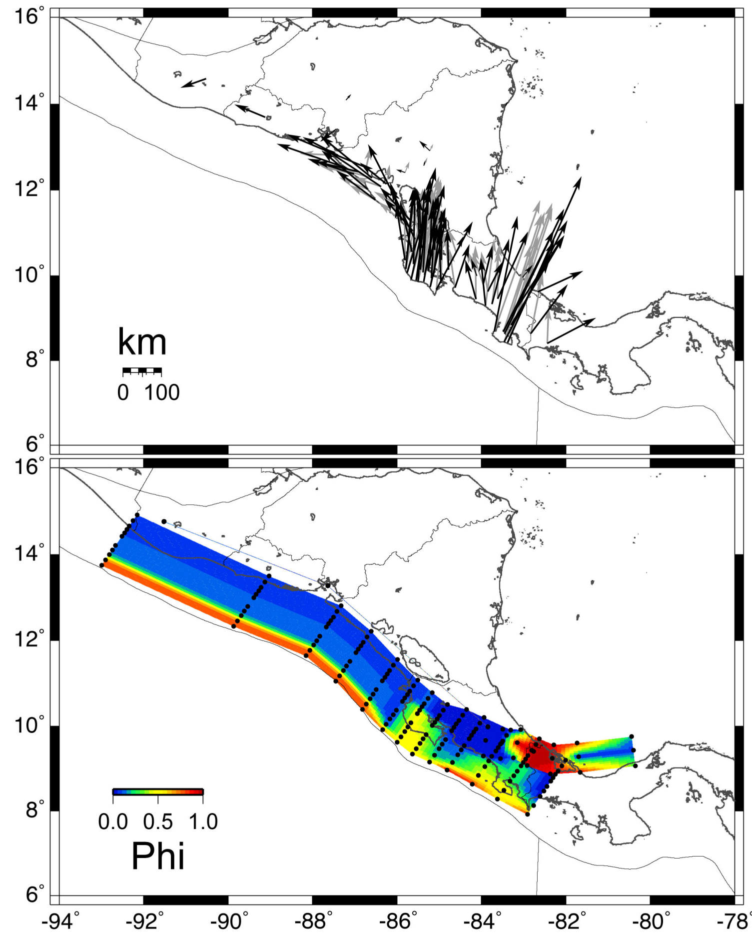
- DEFNODE/TDEFNODE (McCaffrey, 1996)
- GPS velocities and earthquake slip vectors
- CO-CA & NZ-CA Euler vectors
- Joint inversion for coupling on faults and rigid block motion
  - Coupling: ratio of “locked” slip to total plate rate
- 3 - model types
  - Constrained down-dip coupling - (2)
  - No constraints

Phi Constrained Down-dip

Effective Transition Zone



Linear Decrease in Phi



LaFemina et al. (2009; G^3)

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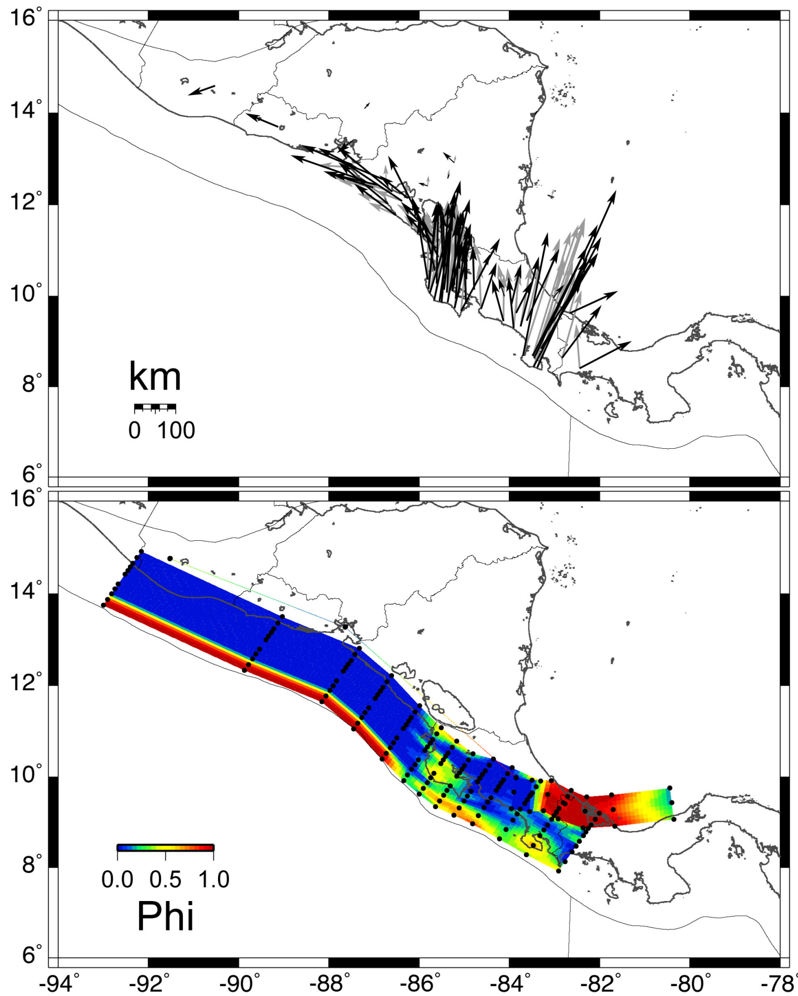
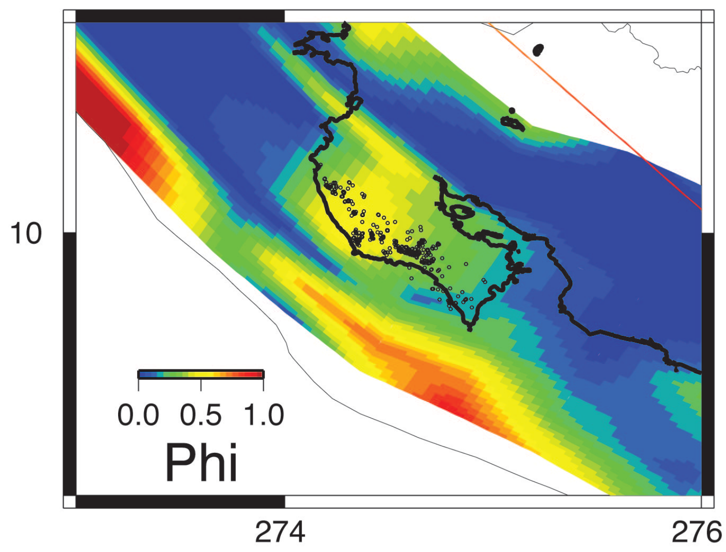
Model Results



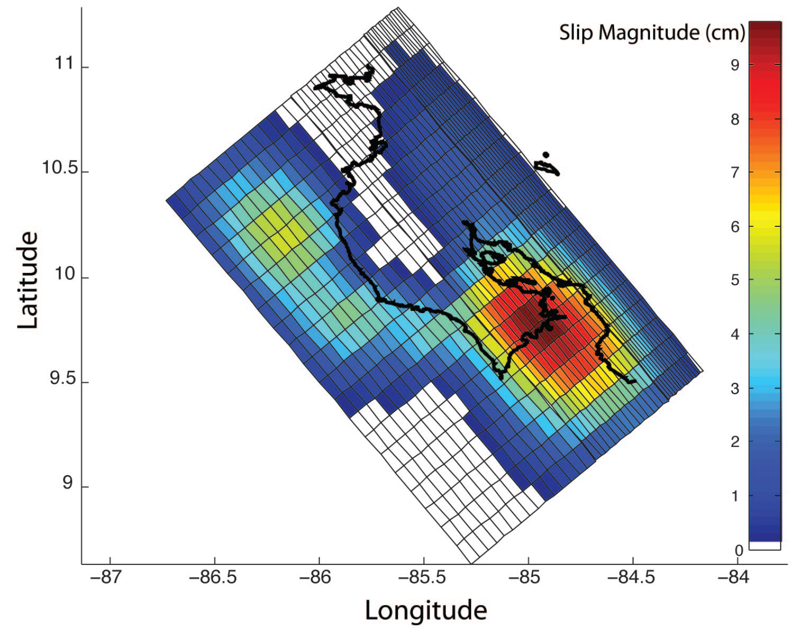
LaFemina et al. (2009; G[3])

- All models predict phi ~0.5 at Osa and Nicoya Peninsulas
- Broad region of coupling at Osa P.
- Pattern of phi (model 3) at Nicoya different than results of Norabuena et al. (2004)
- Along strike variability in phi?
- Low & shallow coupling along Nicaragua
- Increase in forearc translation from C. Costa Rica to N. Nicaragua
- No models predict motion away from Cocos Ridge
- Inclusion of CCRDB does not improve model fit
- New estimates of relative plate motion vectors
- Cocos Ridge collision - indentation

Model 3 Vs. 2007 ETS Displacement

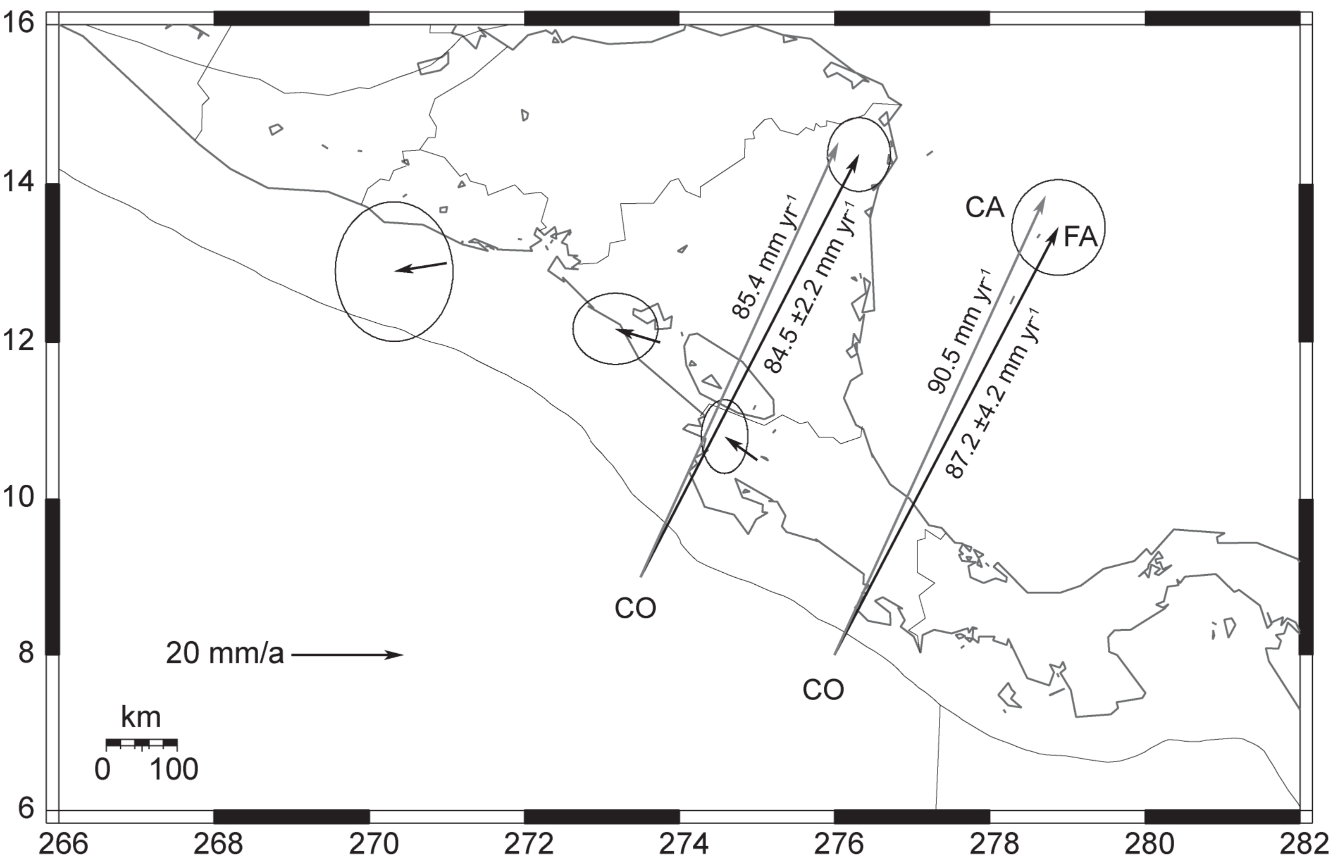


LaFemina et al. (2009; G^3)



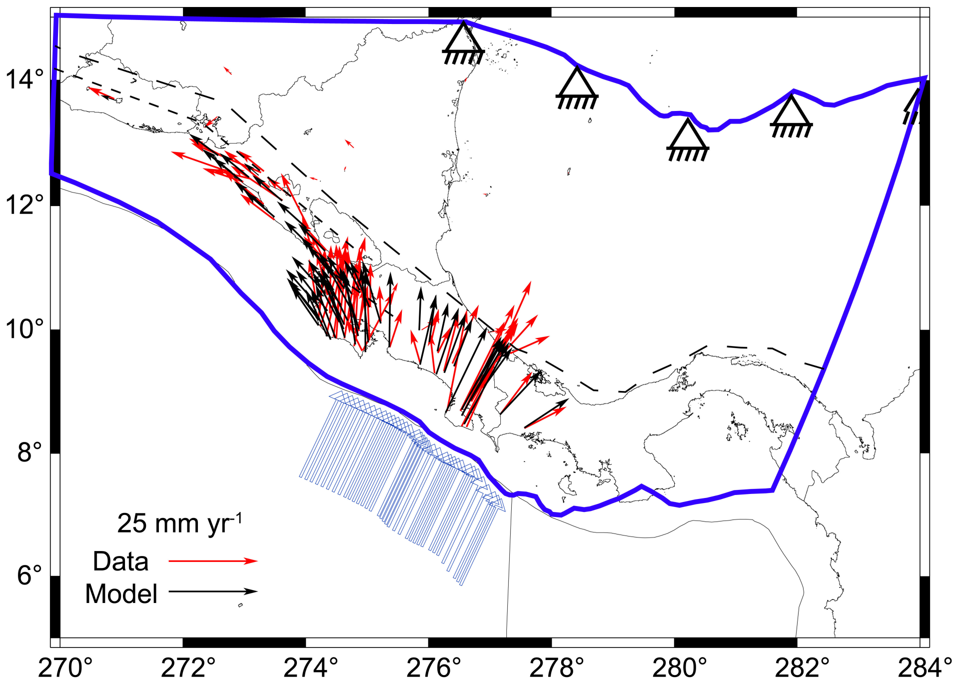
K. Outerbridge (2009)

Relative Plate Motions



LaFemina et al. (2009; G^3)

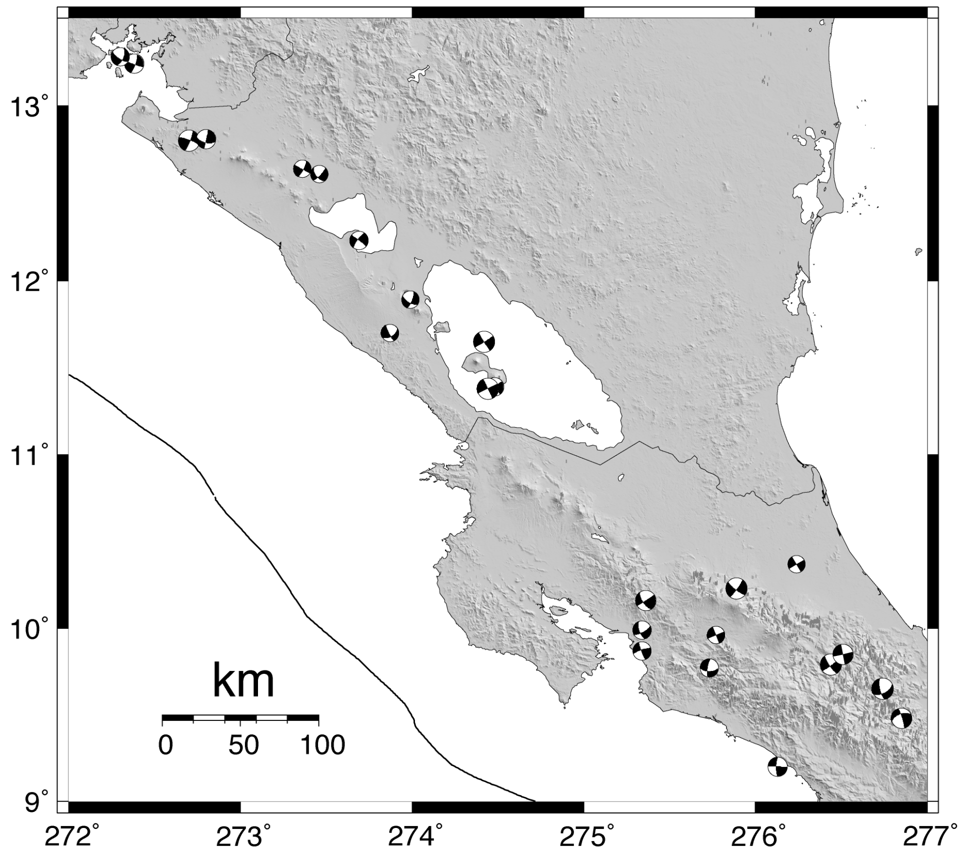
CNS-2 - Cocos Ridge Collision



LaFemina et al. (2009; G3)

- FEM of Ridge Collision (GTECTON)
  - Spherical shell elements
  - Variable rheology b/w forearc/arc (viscoelastic) and Caribbean crust (elastic)
  - Low-friction faults along arc aid in accommodating forearc motion
  - North fixed; East and west free
  - Velocity boundary condition - CNS-2 - Cocos Ridge crust
- Captures main features of velocity field and long-term deformation
  - High rates inboard CR
  - Forearc transport

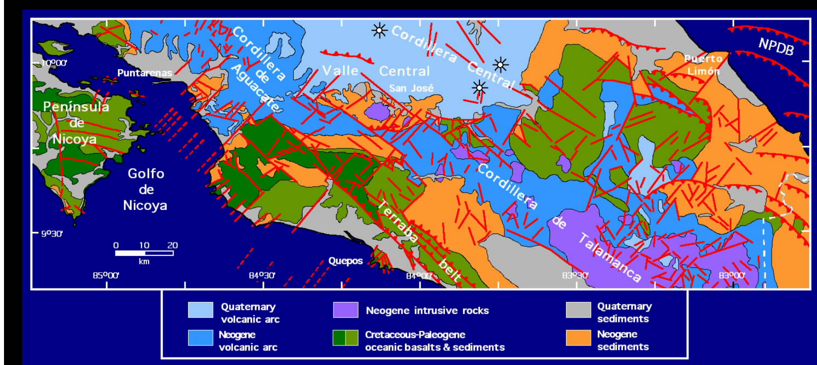
Fore-arc Motion



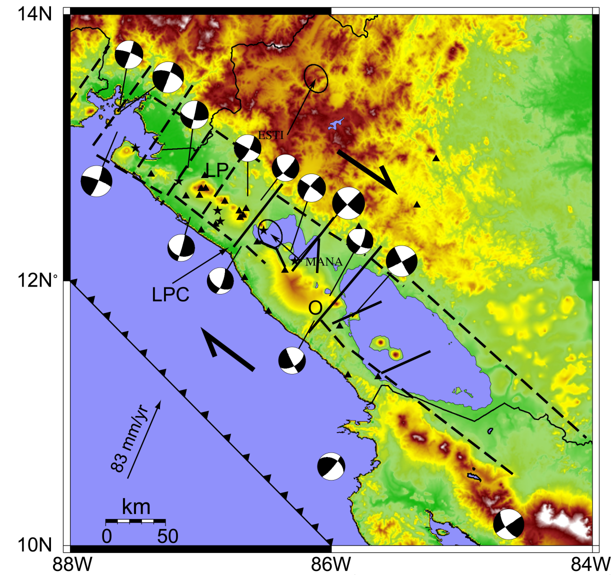
LaFemina (2011; in revision G^3)

- Oblique Convergence or Cocos Ridge collision?
- Upper plate earthquake focal mechanisms (e.g., Molnar & Sykes, 1969)
- Upper plate deformation
  - NW, NE & N - trending faults and volcanic alignments

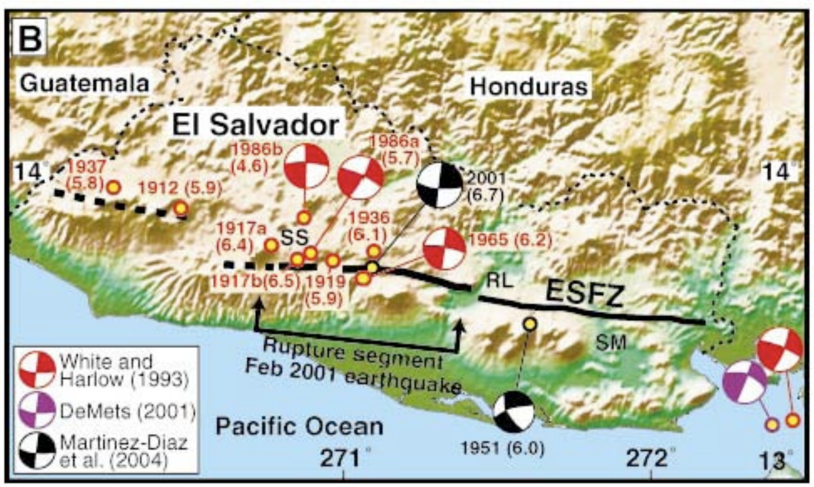
Fore-arc Motion



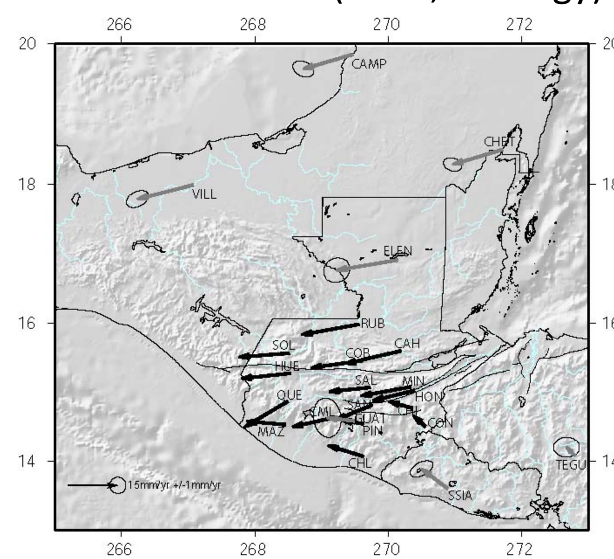
Marshall et al. (2002)



LaFemina et al. (2002; Geology)



Corti et al. (2005)



Lyon-Caen et al. (2006)

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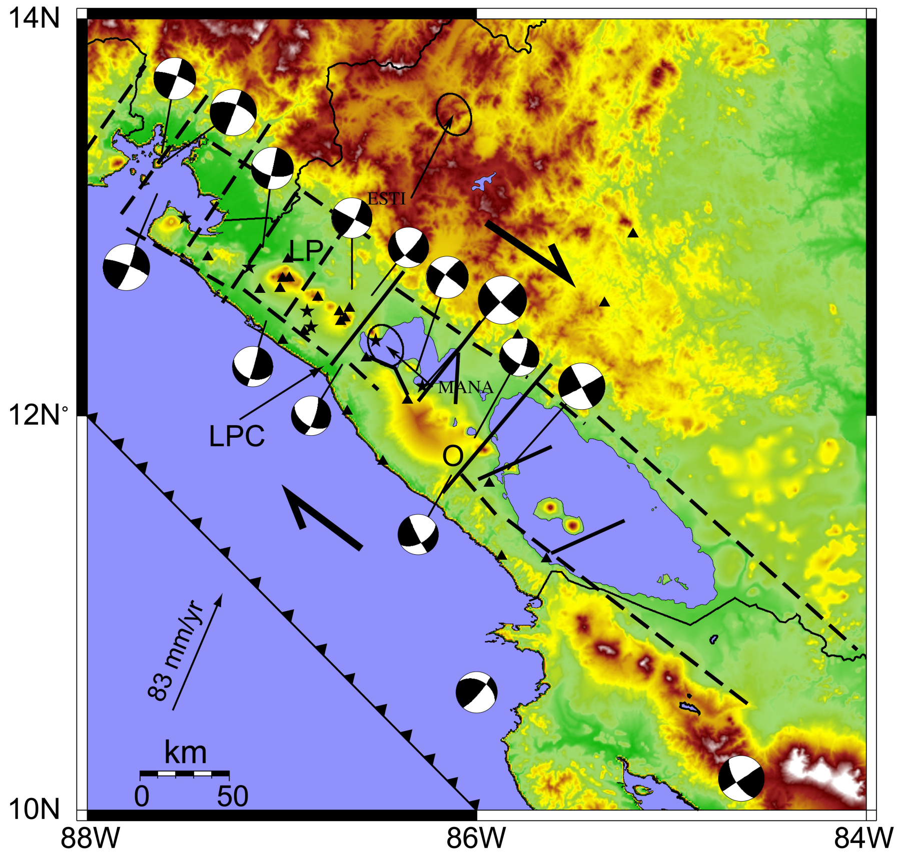
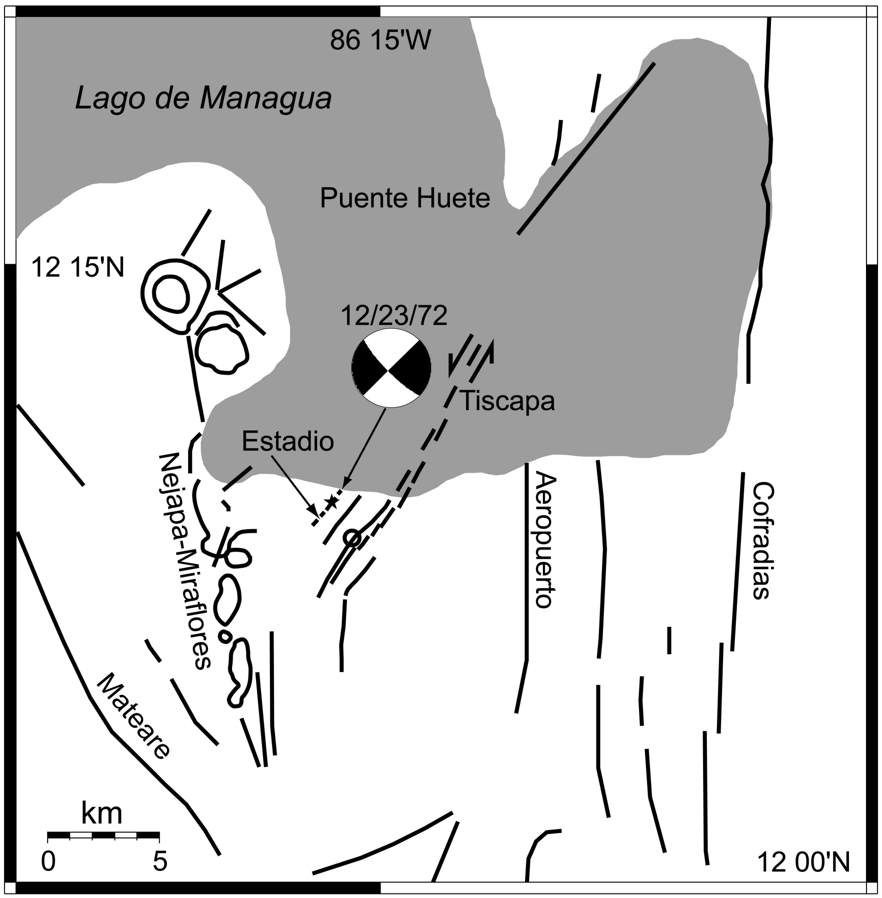
Central Costa Rica to Nicaraguan Fore-arc Motion



LaFemina et al. (2002) *Geology*

- Focal mechanisms are consistent w/ NE or NW trending fault planes
- Aftershocks and surface ruptures trend NE
- Vertical axis block rotation - "bookshelf" faulting

Managua Graben



LaFemina et al. (2002) *Geology*

- March 31, 1931
- December 23, 1972
  - >11,000 people killed
  - ~$1 billion in damage

Maribios Range & Apoyo-Granada

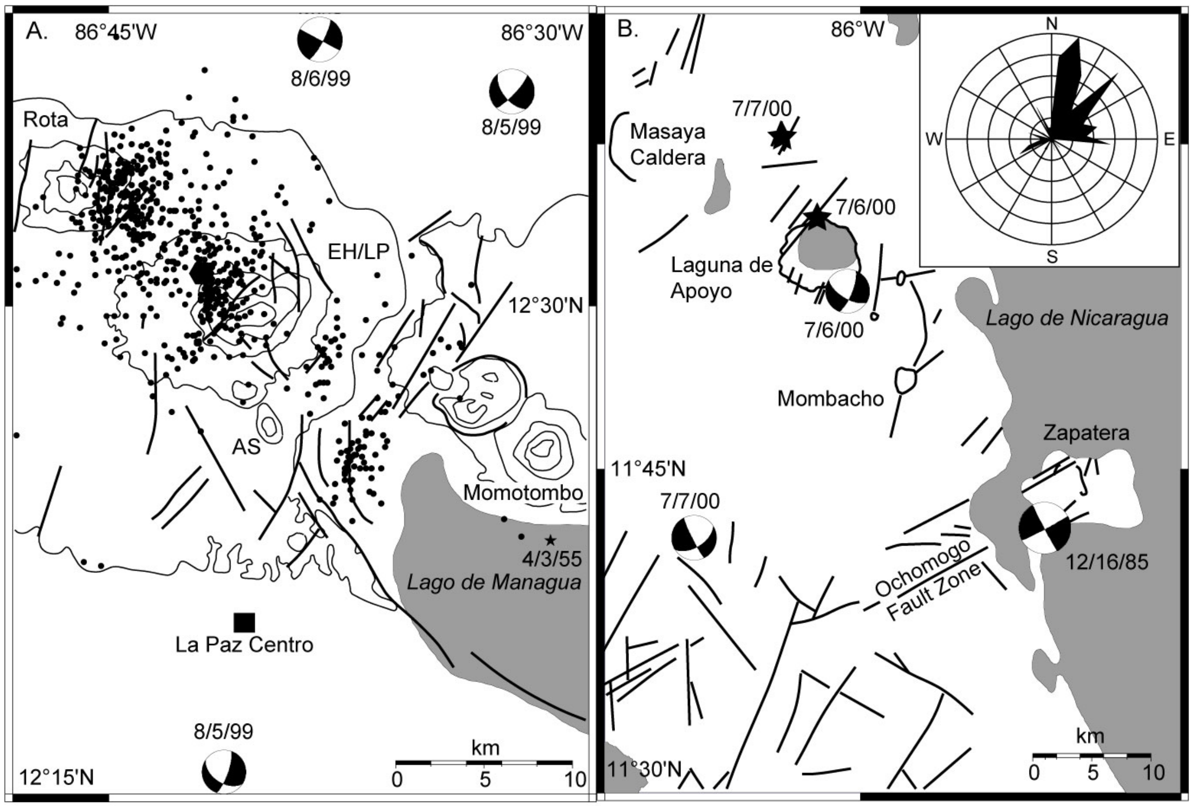
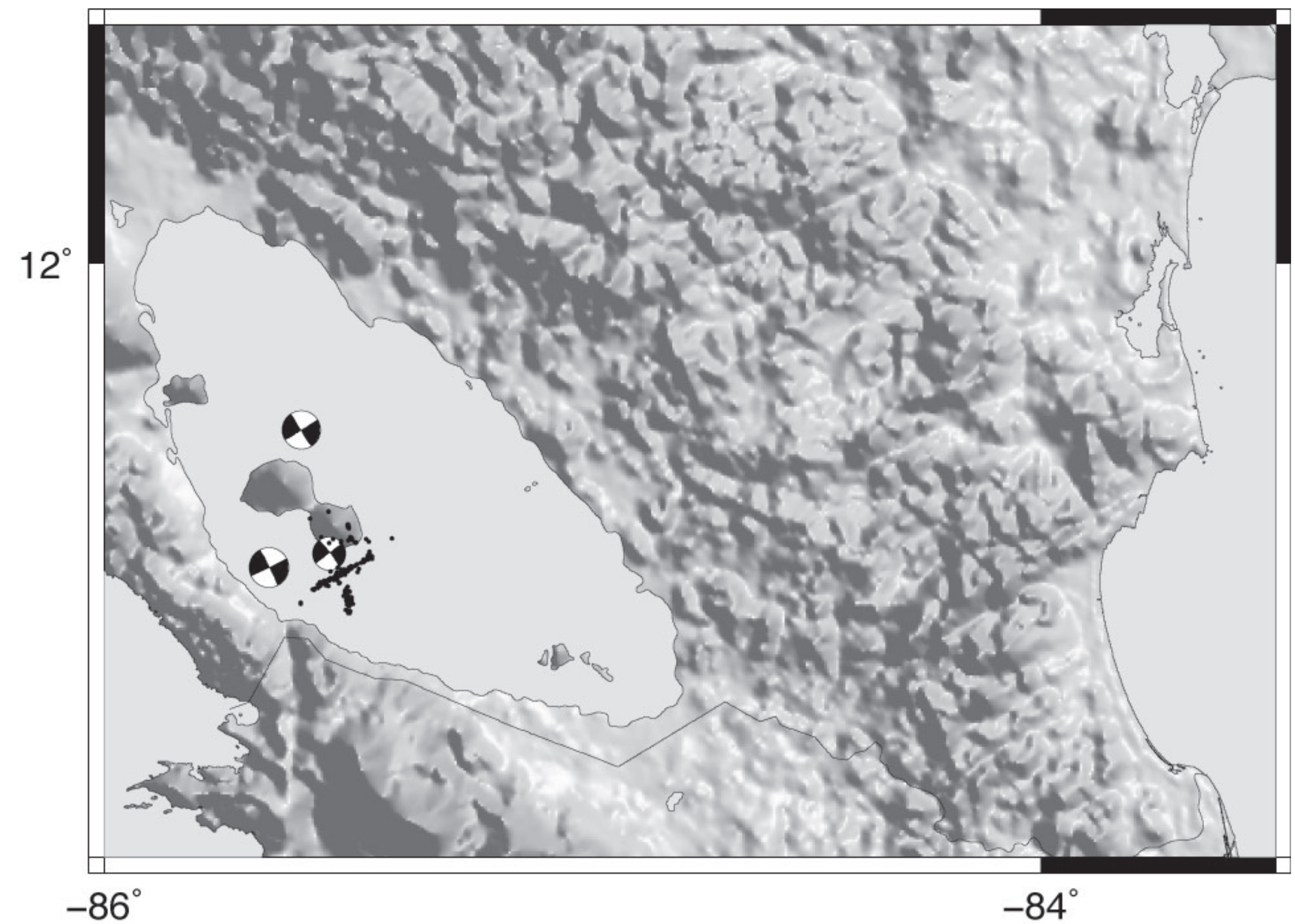


Figure 3a and b. La Femina et al., (2002)

Ometepe Fault Zone

1) 2005 M_w 6.3 earthquake
2) Aftershocks indicate NE trending fault and N trending fault
3) NE-trend is parallel with topographic lineaments in backarc



LaFemina (2011; in revision G^3)

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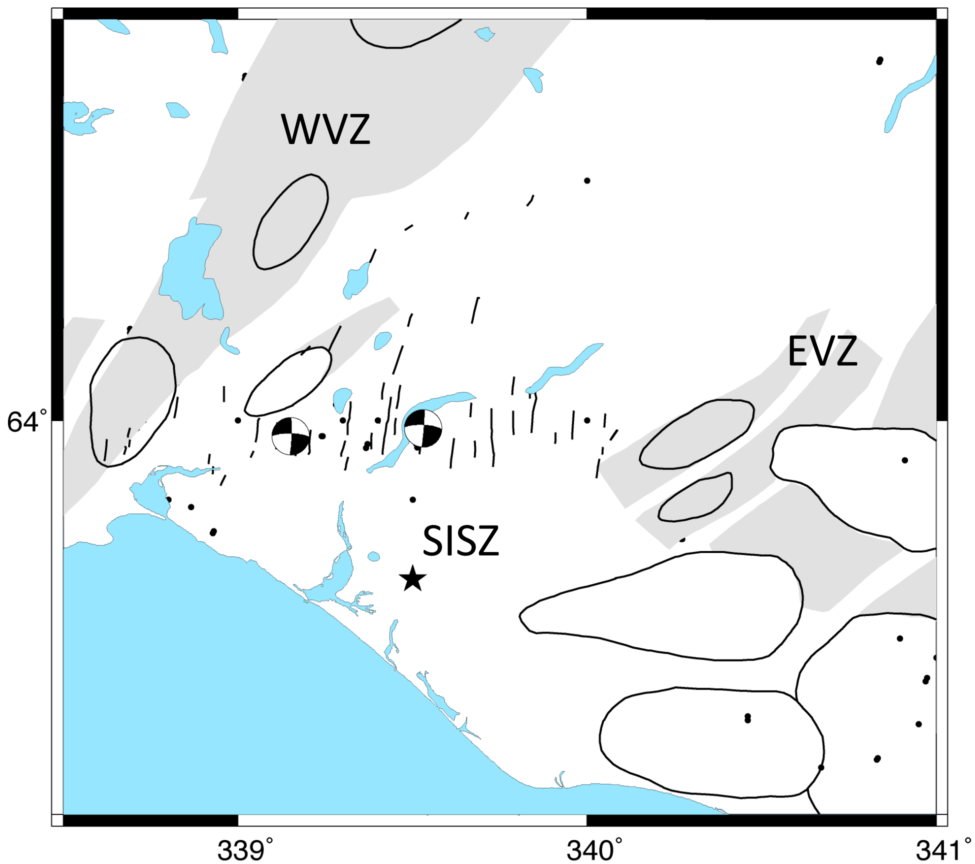
Nicaraguan Fault Slip Rates

Table 1. Data for Quaternary faults in the vicinity of Managua, Nicaragua

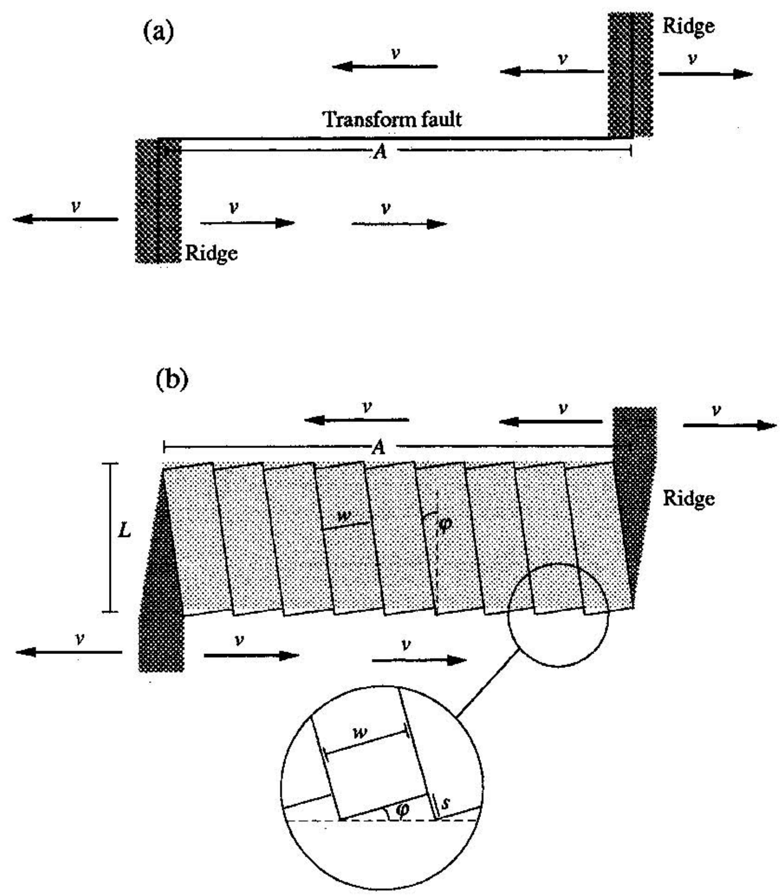
Number	Name of fault	Sense of movement	Time of most recent movement	Slip rate (mm/yr)
NI-01	La Pelona fault zone	Unknown, normal component	<15 ka	Unknown, probably 0.2-1.0
NI-02	La Paz Centro fault zone	Unknown, normal component	<15 ka	Unknown, probably 0.2-1.0
NI-03	Mateare fault zone	Unknown, normal component	<1.6 Ma?	Unknown, probably 0.2-1.0
NI-04	Asososca-Acahualinca and San Judas faults (Managua graben)	Unknown, normal component	<15 ka	Unknown, probably 0.2-1.0
NI-05	Estadio fault	Left-lateral (sinistral)	Historic (1931)	Unknown, probably 0.2-1.0
NI-06	Tiscapa fault	Left-lateral (sinistral)	Historic (1972)	Unknown, probably 0.2-1.0
NI-07	Aeropuerto fault	Oblique-normal slip (lateral sense unknown)	Historic (1650 to 1880)	Unknown, probably 0.2-1.0
NI-08	Unnamed faults, eastern Managua graben	Oblique-normal slip (lateral sense unknown)	<15 ka, maybe historic (1772?)	Unknown, probably 0.2-1.0
NI-09	Cofradia fault, eastern Managua graben	Normal?	<15 ka	1.2 mm/yr
NI-10	Ochomogo fault zone	One right lateral (dextral), others not reported	<15 ka	Unknown, probably 0.2-1.0

USGS OFR -00-0437; Cowan et al. (2000)

Iceland Analog



LaFemina (2011; in revision G3)



Sigmundsson et al. (1995)

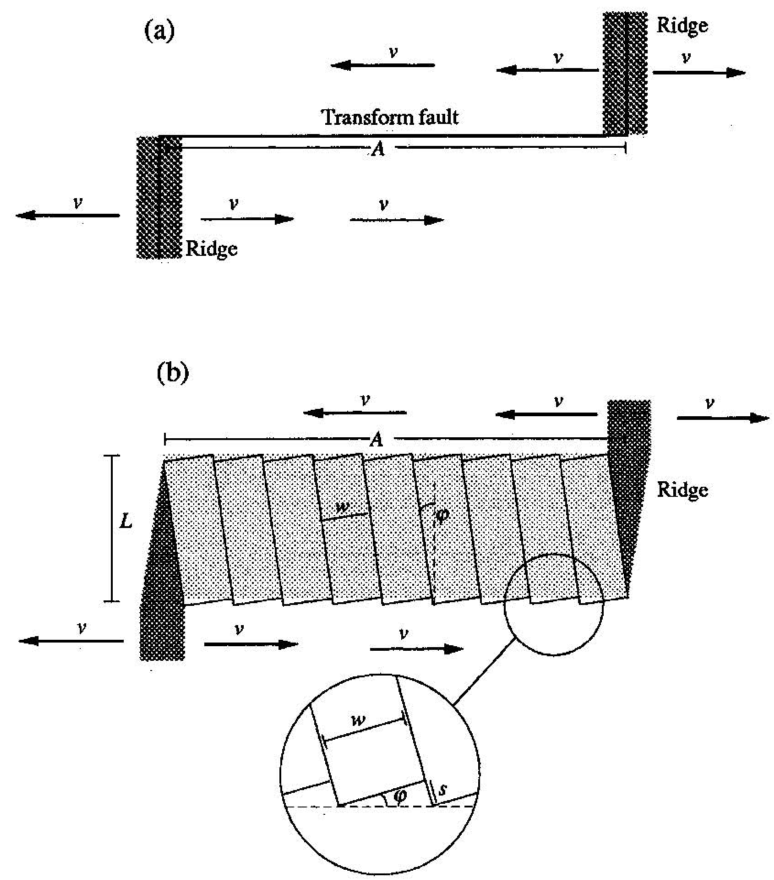
Iceland Analog

Rotation rate of faults (urad yr^{-1}):

$$\dot{\varphi} = \frac{2v}{L}$$

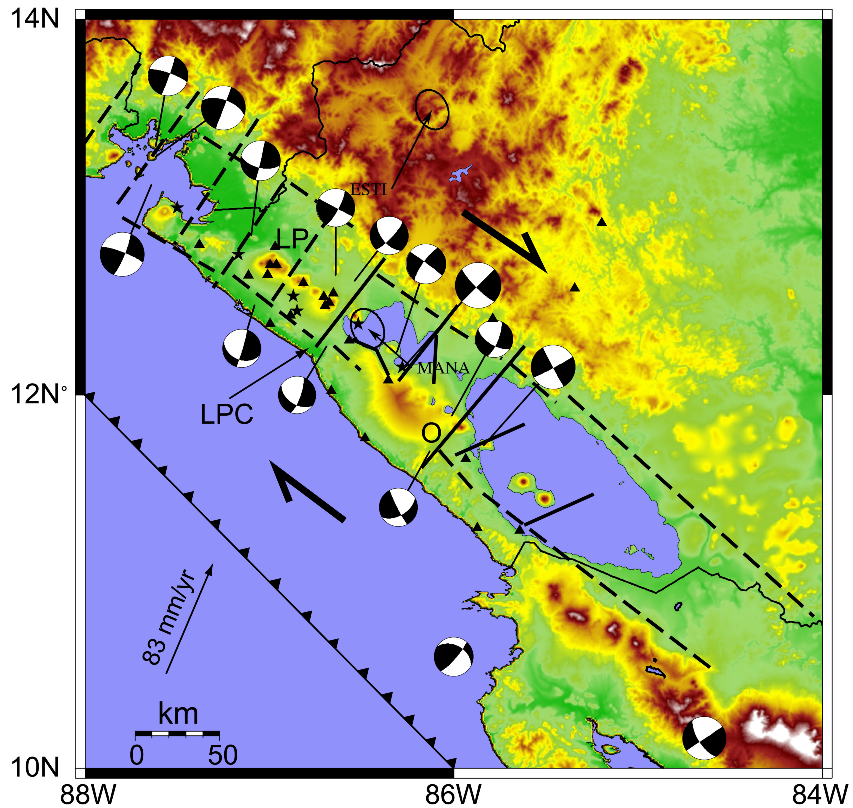
Slip rate of faults (mm yr^{-1}):

$$\dot{s} = w\dot{\varphi}$$



Sigmundsson et al. (1995)

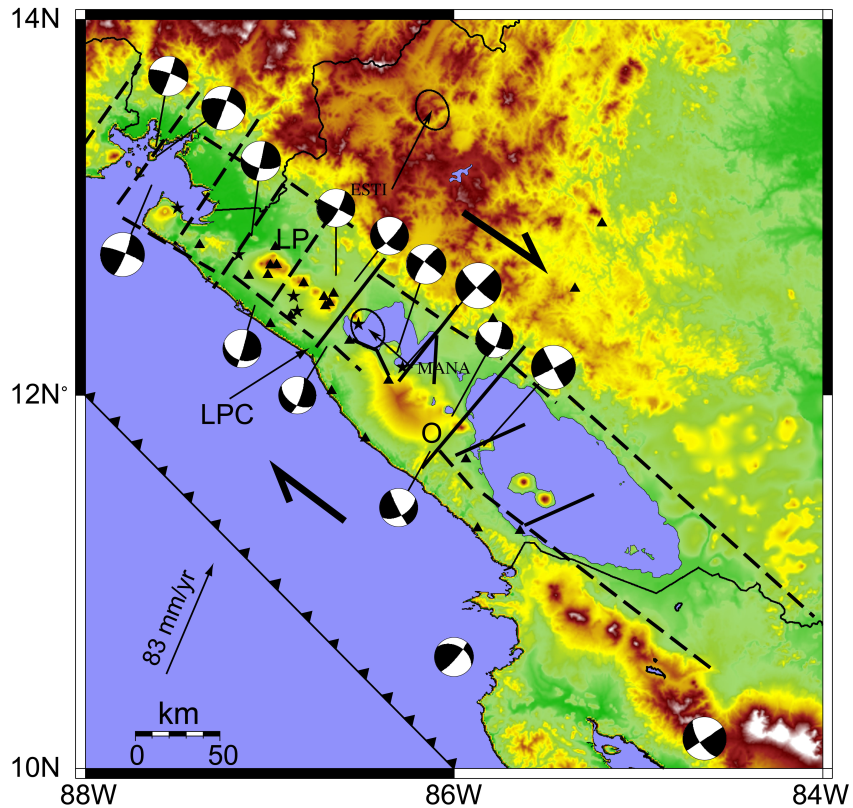
Central Costa Rica to Nicaraguan Fore-arc Motion



LaFemina et al. (2002) *Geology*

- Fault zone parameters
  - $2v = 8$ mm yr^{-1}
  - L = 20-40 km
  - W = 39 km (avg)
- $\varphi = 2 \times 10^{-7}$ urad yr^{-1}
- S = ~8.5-17.5 mm yr^{-1}

Central Costa Rica to Nicaraguan Fore-arc Motion



LaFemina et al. (2002) *Geology*

- Geometric Moment rate:

$$\dot{M}_o = 2vAD$$

- Efficiency
  - Single margin-parallel strike slip fault
    - 2.77×10^7 m^3 yr^{-1}
  - Bookshelf faults
    - 2.62×10^7 m^3 yr^{-1}
- Compared to Geometric M_o rate from seismicity
  - 1.01×10^7 m^3 yr^{-1}

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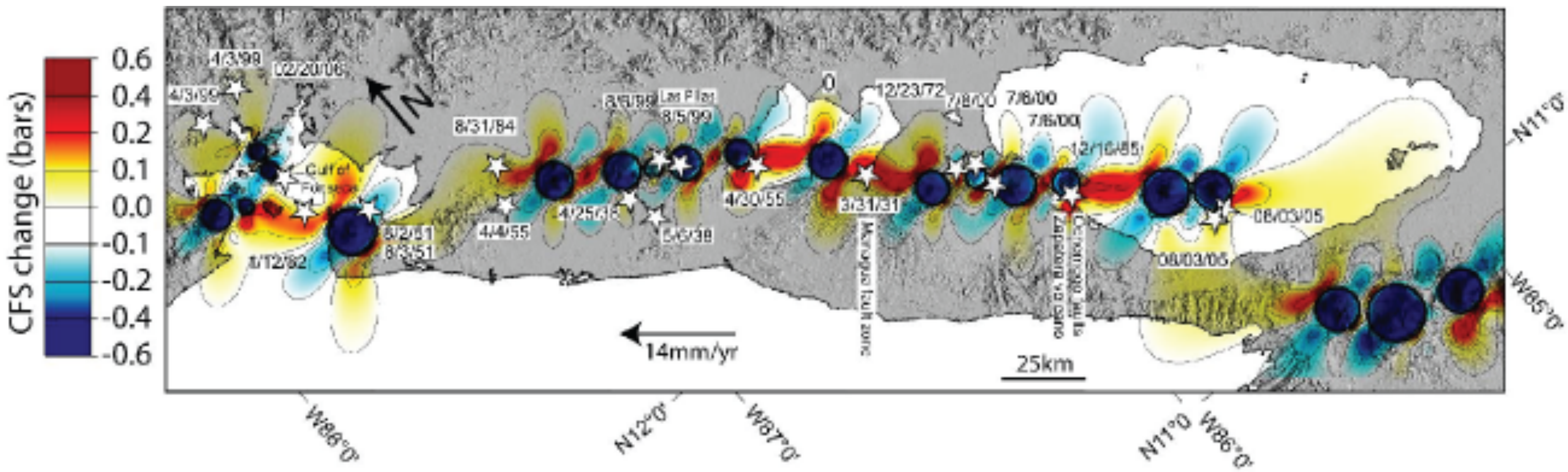
Why Bookshelf Faulting?



Cailleau, LaFemina & Dixon (2007)

Fig.4

- Stress increase between volcanoes
- Reactivation of Miocene structures

Conclusions

- Elastic strain accumulation; MAT, NPDB and forearc
- Slip partitioning between plate boundary and fore arc (80 mm/yr) and North Panama deformed belt & Caribbean (~7-9 mm/yr)
- Fore arc translation symmetrical about Cocos Ridge to northwest and southeast
  - ~8.5 mm/yr in Nicaragua (new results indicate ~11 mm/yr)
  - ~9-10 mm/yr eastward motion of Panama
- Bookshelf faulting is a feasible mechanism and has implications for seismic hazard assessment