Reply: Central American forearc slip revisited

Charles DeMets
Department of Geology and Geophysics, UW-Madison, Madison, Wisconsin, USA

Received 25 April 2002; revised 5 June 2002; accepted 5 June 2002; published XX Month 2002.

[1] I thank Guzman-Speziale and Gomez (GSG02) for their comments on DeMets (2001) (DM2001). GSG02 do not challenge the fundamental observation reported by DM2001, namely, that earthquake slip directions along the Middle America trench between western Guatemala and Costa Rica are rotated ~10° clockwise relative to the Cocos-Caribbean convergence direction. However, they dispute the interpretation that this oblique convergence causes dextral shear across the Central American forearc in this region [*White*, 1991; *DeMets*, 2001]. Below, I address their reservations. *INDEX TERMS:* 8107 Tectonophysics: Continental neotectonics; 8110 Tectonophysics: Continental tectonics—general (0905); 8123 Tectonophysics: Dynamics, seismotectonics; 8150 Tectonophysics: Evolution of the Earth: Plate boundary—general (3040)

1. Convergence Obliquity and Forearc Motion

[2] GSG02 begin by asserting that the trench-normal directions used by DM2001 are either in error or misused and use their own directions to derive along-arc slip rates that vary from 0–35 mm yr^{-1}. I re-derived trench-normal directions by fitting great circles to one-degree arc segments of the trench axis extracted from the *Sandwell and Smith* [1997] 2-minute topographic grid. The revised directions (solid squares in Figure 1) rotate counterclockwise from N30°E at 94°W to N21°E at 88°W, in accord with the observed curvature of the trench axis offshore from 94°W–88°W. In contrast, directions derived by GSG02 rotate clockwise from 94°W–88°W, opposite that expected. The revised directions agree well with those used by DM2001 everywhere except from 90.5–89°W, where they are ~5° closer to trench-normal. The convergence obliquity is hence somewhat smaller than shown by DM2001 along this limited trench segment, as proposed by GSG02. The more relevant observation of a systematic bias between the earthquake slip directions and plate convergence direction is unchanged.

[3] GSG02 use their revised trench-normal directions to estimate that forearc slip rates are slow or zero everywhere except in Nicaragua, where they estimate a rate of 35 mm yr^{-1} from the angle between the trench-normal and predicted Cocos-Caribbean directions. However, the magnitude of forearc slip instead depends almost entirely on the angle between the predicted plate convergence direction and the convergence direction given by shallow-thrust earthquakes that record motion of the subducting plate relative to the overlying forearc [e.g., *Jarrard*, 1986; *McCaffrey*, 1992]. A kinematically rigorous derivation of the slip rate offshore from Nicaragua, shown in Figure 2 of DM2001, yields 14 ± 5 mm yr^{-1} of dextral forearc translation.

2. Evidence for Forearc Slip: Nicaragua

[4] GSG02 state that geologic and seismologic evidence for left-lateral strike-slip motion along NE-striking faults that offset the volcanic arc, particularly in Nicaragua, is inconsistent with NW-directed forearc translation. This is true if such motion can only be accommodated via right-lateral, NW-striking faults. However, *LaFemina et al.* [2002] interpret the same observations as evidence that clockwise rotating forearc blocks are caught in a zone of dextral shear driven by northwestward motion of the forearc. Opposite-sense slip along cross-faults is observed in other zones of distributed shear [e.g., *Hudnut et al.*, 1989] and does not constitute convincing evidence against dextral shear of the Central American forearc.

[5] The motion of the continuous GPS site MANA along the volcanic arc (Figure 1) constitutes additional evidence for NW-directed forearc motion. Relative to the Caribbean plate, MANA moves 7 ± 3 mm yr^{-1} to the northwest, parallel to the volcanic arc. Assuming NW-directed forearc transport, sites within ~50 km of locked faults along or near the volcanic arc should experience significant elastic strain and should exhibit NW-directed motion relative to the rigid Caribbean plate interior, as does MANA. That the observed slip of 7 ± 3 mm yr^{-1} at MANA is roughly half the 14 ± 5 mm yr^{-1} predicted forearc slip rate is consistent with a model in which roughly half of the elastic strain is stored on either side of the volcanic arc.

[6] GSG also state that DM2001 implicitly assumes that all strike-slip earthquakes in the vicinity of the volcanic arc record right-lateral slip along NW-striking faults. To the contrary, DM2001 explicitly states that "Most (not all) of these (volcanic arc) earthquakes have accommodated trench-parallel, dextral strike-slip motion", as concluded by *White and Harlow* [1993] from their study of the regional seismicity.

3. Deformation Northwest of Nicaragua

[7] GSG02 express reservations about the existence of significant forearc translation west of ~88°W given that convergence obliquity from ~92°W–89°W is small (Figure 1) and there is no evidence for crustal thickening or other upper plate deformation at the leading edge of the hypothesized forearc sliver. The latter is not problematic given that the Middle America trench and/or Caribbean-North America plate boundary faults could accommodate convergent motion along the leading edge of a NW-translating sliver. GSG02 nonetheless raise useful questions about the appropriate model for present-day deformation

0094-8276/02/2002GL015384$05.00

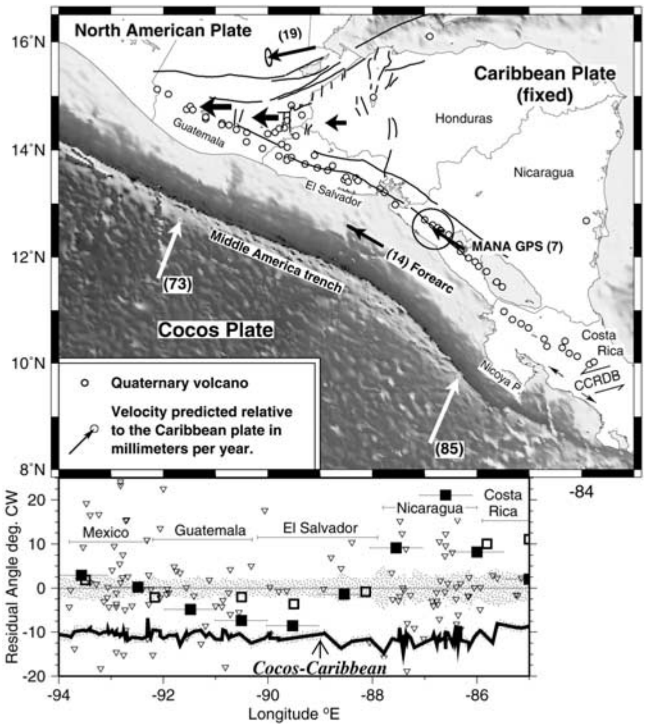

Figure 1. Upper - Volcano-tectonic setting of western Central America. All arrows show motion relative to the Caribbean plate. Velocities and uncertainties are from DM2001 except for the updated GPS velocity at MANA (see text). CCRDB is Central Costa Rica deformed belt [*Marshall et al.*, 2000], whose intersection with the trench marks the SE limit of the study area. Lower - Predicted Cocos-Caribbean motion from DM2001, updated trench-normal directions (solid squares), trench-normal directions from DM2001 (open squares), and horizontal slip directions of shallow-thrust subduction earthquakes (triangles) shown as residual angles from the directions predicted by the pole that best fits the earthquake slip directions from 94–85.5°W. Shaded areas show 1σ uncertainties.

in Guatemala and southern Mexico. Several observations relevant to the present debate are as follows: (1) slip directions of subduction earthquakes from 94–90°W are rotated 5–15° clockwise from the Cocos-Caribbean direction (DM2001), (2) east-west extension occurs across grabens in Honduras and central and eastern Guatemala [*Guzman-Speziale et al.*, 1989], and (3) upper-crustal earthquakes in El Salvador and south-central Guatemala are focused along the volcanic arc [*White*, 1991; *White and Harlow*, 1993].

[8] A model in which westward motion of Guatemala occurs across a zone of distributed extension east of the volcanic arc, possibly combined with NW-directed forearc transport in El Salvador and Guatemala is consistent with the above observations. Consideration of the relevant linear velocities (Figure 2 from DM2001) shows that motion of a westward-translating Guatemalan "block" relative to the Caribbean plate interior would deflect the slip directions of shallow-thrust, subduction earthquakes offshore from Guatemala and parts of El Salvador (Figure 1) clockwise from the Cocos-Caribbean convergence direction, as is observed. Suitable geodetic measurements are needed to determine whether the average direction determined from the scattered earthquake slip directions from ~92°W–89°W accurately represents the present motion of the Cocos plate beneath the forearc, and if so, whether extension across Honduras and Guatemala is sufficient to explain the entire observed bias in the subduction slip directions or whether northwest-directed forearc translation must also be invoked, as suggested by the occurrence of non-volcanic earthquakes along the volcanic arc in this region.

[9] **Acknowledgments.** This work was funded by NSF grant EAR-0003550.

References

DeMets, C., A new estimate for present-day Cocos-Caribbean plate motion: Implications for slip along the Central American volcanic arc, *Geophys. Res. Lett.*, *28*, 4043–4046, 2001.

Guzman-Speziale, M., W. D. Pennington, and T. Matumoto, The triple junction of the North America, Cocos, and Caribbean plates: Seismicity and tectonics, *Tectonics*, *8*, 981–997, 1989.

Hudnut, K. W., L. Seeber, and J. Pacheco, Cross-fault triggering in the November 1987 Superstition Hills earthquake sequence, southern California, *Geophys. Res. Lett.*, *16*, 199–202, 1989.

Jarrard, R. D., Terrane motion by strike-slip faulting of forearc slivers, *Geology*, *14*, 780–783, 1986.

LaFemina, P. T. H. Dixon, and W. Strauch, Accommodation of trench-parallel block motion due to oblique subduction in Nicaragua by bookshelf faulting, *Geology*, *30*, 751–754, 2002.

Marshall, J. S., D. M. Fisher, and T. W. Gardner, Central Costa Rica deformed belt: Kinematics of diffuse faulting across the western Panama block, *Tectonics*, *19*, 468–492, 2000.

McCaffrey, R., Oblique plate convergence, slip vectors, and forearc deformation, *J. Geophys. Res.*, *97*, 8905–8915, 1992.

Sandwell, D. T., and W. H. F. Smith, Marine gravity anomaly from Geosat and ERS 1 altimetry, *J. Geophys. Res.*, *102*, 10,039–10,054, 1997.

White, R. A., Tectonic implications of upper-crustal seismicity in Central America, in *Neotectonics of North America, Decade Map*, vol. 1, edited by D. B. Slemmons, E. R. Engdahl, M. D. Zoback, and D. D. Blackwell, pp. 323–328, Geol. Soc. Am., Boulder, 1991.

White, R. A., and D. H. Harlow, Destructive upper-crustal earthquakes of Central America since 1900, *Bull. Seismol. Soc. Am.*, *83*, 1115–1142, 1993.

C. DeMets, Department of Geology and Geophysics, UW-Madison, 1215 W Dayton St, Madison, WI 53706, USA. (chuck@geology.wisc.edu)