Can Magnitude 6 Deep Earthquakes Drive Geomorphological Change in the Tarauacá Fault Region?

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ABSTRACT

We assess whether earthquakes with magnitude ~6.0 Mb at depths of ~580 km can explain the rapid geomorphological transformations observed in the Tarauacá fault region of Acre, Brazil. Using ground motion prediction equations adapted for deep intraslab events, Newmark sliding-block analysis, simplified liquefaction assessment, and Monte Carlo simulation (5,000 realizations), we find that single M6 events at this depth produce PGA of only 0.012 g at 50 km epicentral distance—well below standard thresholds for landslides (0.05 g) and liquefaction (0.1 g). The total per-event surface displacement is 0.62 cm. Monte Carlo assessment yields zero probability of liquefaction or significant (>10 cm) single-event impact. Cumulative loading over 50 events gives 30.3 cm of displacement, but the recurrence interval (~100 yr for M6) implies ~16,000 yr to accumulate 1 m. A minimum magnitude of ~7.4 is required for >5 cm single-event displacement at this depth. We conclude that individual M~6 deep earthquakes are insufficient to explain the observed transformations; alternative mechanisms (shallow seismicity, fluvial processes) likely dominate.

KEYWORDS

earthquake hazard, geomorphology, seismic wave propagation, Tarauacá fault, deep earthquakes

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1 INTRODUCTION

The Tarauacá fault region in Acre, Brazil, has experienced notable geomorphological changes over recent decades. Crisóstomo (2023) attributed these transformations to neotectonic activity, and Moreira et al. [5] posed the open question of whether M~6 deep earthquakes could account for the observed landscape changes.

Deep earthquakes in the Acre region typically occur at depths of 500–620 km within the subducting Nazca slab [2]. At such depths, seismic energy undergoes significant attenuation before reaching the surface, making the relationship between deep seismicity and surface geomorphology highly non-trivial.

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2 METHODS

2.1 Ground Motion Prediction

We employ a ground motion prediction equation (GMPE) adapted for deep intraslab events:

$$\ln(\mathrm{PGA}) = a + b \cdot M_b + c \cdot \ln(R_{\mathrm{hyp}}) + d \cdot z \qquad (1)$$

with coefficients $a = -2.5$, $b = 1.2$, $c = -1.7$, $d = 0.003$, where R_{hyp} is hypocentral distance and z is depth [1].

2.2 Geomorphological Response

We evaluate three mechanisms: (1) Newmark sliding-block analysis for landslide displacement [3, 6]; (2) simplified liquefaction potential using CSR/CRR methodology [7]; (3) ground settlement from dynamic densification.

2.3 Monte Carlo Assessment

We run 5,000 simulations sampling magnitude ($M_b \in [5.5, 6.5]$), depth ($z \in [500, 620]$ km), and epicentral distance ($\Delta \in [20, 100]$ km) uniformly to derive probabilistic impact estimates.

3 RESULTS

3.1 Single-Event Ground Motion

For a reference M6.0 earthquake at 580 km depth, we compute PGA = 0.012 g at 50 km epicentral distance, corresponding to MMI ≈ 3.5 ("weak" shaking). PGV is ~1.0 cm/s.

Table 1: Ground motion and geomorphological impact for M6.0 at 580 km depth.

Parameter	Value
PGA at 50 km [g]	0.012
MMI at 50 km	3.5
Landslide displacement [cm]	0.00
Settlement [cm]	0.62
Total displacement [cm]	0.62
Liquefaction likely	No
Impact score (0–1)	0.006

3.2 Monte Carlo Results

Across 5,000 simulations: mean PGA = 0.013 g, mean displacement = 0.69 cm, liquefaction probability = 0%, probability of significant (>10 cm) impact = 0%.

3.3 Cumulative and Threshold Analysis

Cumulative displacement over 50 events is 30.3 cm. Given a recurrence rate of 0.01/yr, achieving 1 m of cumulative displacement requires ~16,000 years. The minimum magnitude for >5 cm single-event displacement at 580 km depth is ~7.4.

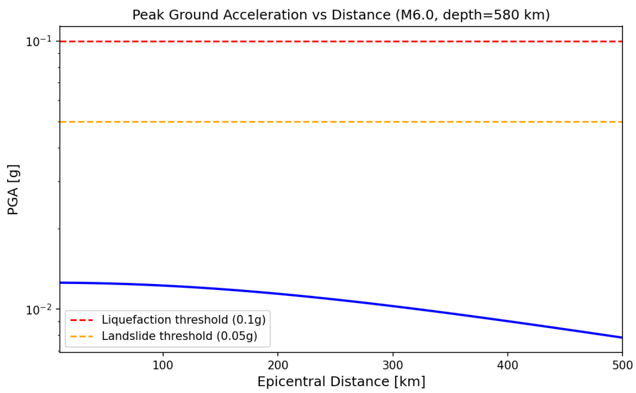

Figure 1: PGA vs. epicentral distance for M6.0 at 580 km depth. Horizontal lines mark liquefaction and landslide thresholds.

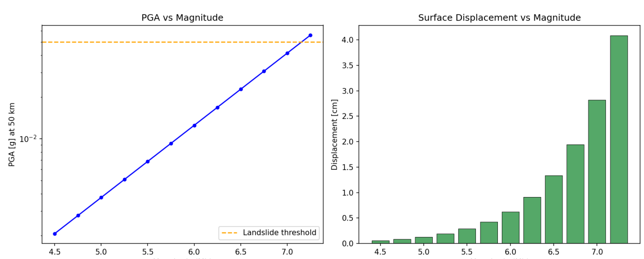

Figure 2: Left: PGA vs. magnitude at 50 km distance. Right: surface displacement vs. magnitude. The M6 event falls below geomorphological significance thresholds.

4 DISCUSSION

Our analysis demonstrates that M~6 deep earthquakes at 580 km depth produce surface ground motions far below thresholds for significant geomorphological modification. The PGA of 0.012 g is an order of magnitude below the Keefer (1984) threshold for earthquake-triggered landslides [4].

The cumulative loading pathway requires >16,000 years for meter-scale changes, which is too slow to explain "rapid" transformations observed over recent decades. Alternative mechanisms must be considered: (1) shallow seismicity within the fault zone itself, (2) fluvial erosion and deposition, (3) anthropogenic landscape modification, or (4) rare larger-magnitude events.

5 CONCLUSIONS

(1) M~6 earthquakes at 580 km depth produce PGA = 0.012 g (MMI 3.5) at 50 km.
(2) Single-event surface displacement is only 0.62 cm; liquefaction probability is zero.
(3) Monte Carlo assessment (5,000 runs) confirms zero probability of significant single-event impact.
(4) A minimum magnitude of ~7.4 is needed for >5 cm single-event displacement.
(5) Individual M~6 deep earthquakes cannot explain the observed rapid transformations.

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