Mapping active faults in the northern Andes using Pleiades satellite tri-stereo imagery

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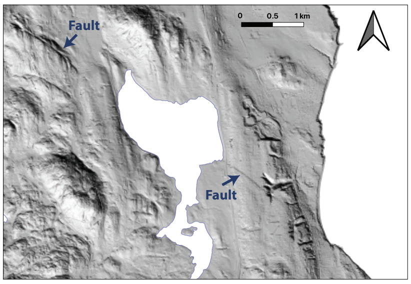
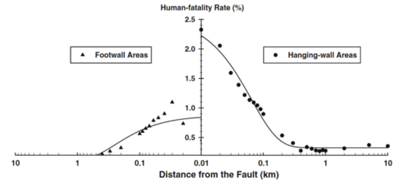
Mapping faults using traditional airborne lidar

Active faults are essential inputs into Probabilistic Seismic Hazard Assessments (PSHA).

Delineating active structures is difficult in low-strain settings or regions with rapid erosion, urban development, or dense vegetation.



Example: Offset drumlin and bedrock scarps along the XEOLXELEK - Elk Lake fault, British Columbia, Canada visible in hillshaded airborne lidar-derived DTM. Lidar from the LidarBC Open Lidar Portal.



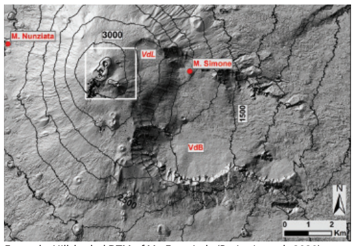
Example: Human fatality rate during an earthquake increased substantially within 200 m of the M 7.7 Chi-Chi earthquake, Taiwan, Pai et al., (2007)

High-resolution Digital Terrain Models (DTMs) can be used to map small topographic scarps and offsets of geomorphic features (0.1 to 5 m) along active faults.

Airborne lidar is traditionally used to create these DTMs but it is prohibitively expensive to collect over large areas.

Airbone lidar can aslo be impossible to collect in some areas due to access restrictions.

Mapping faults using Pleiades



Example: Hillshaded DTM of Mt. Etna, Italy (Proiettie et al., 2020).

High-resolution Pleiades tri-stereo imagery can be used to make ~1 m-resolution DTMs.

Captures a large area for significantly less cost than airborne lidar.

https://cnes.fr/fr/web/CNES-fr/

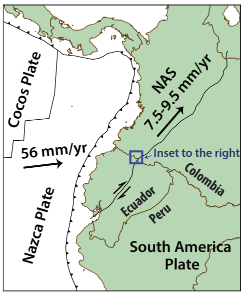
Methodolgy:

1) Define areas of high interest using low resolution DTMs, geodetic data, and seismicity data.

2) Acquire Pleiades tri-stereo 0.5 m-resolution panchromatic images with low cloud-cover for the target areas.

3) Use NASA Ames Stereopipeline to transform stereo-imagery to a DTM.

Case Study: Active faults in the northern Andes of northern Ecuador and southern Colombia



Left: Oblique subduction of the Nazca Plate beneath South America results in northeast motion of the Northern Andean Sliver (NAS).

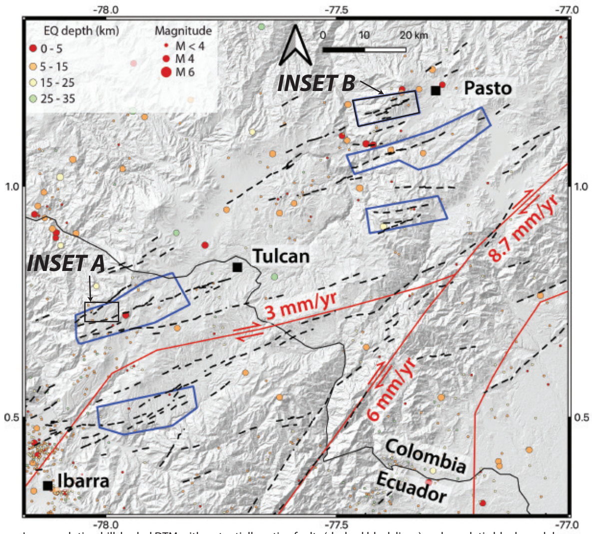
How deformation is accommodated between the NAS and the stable South America Plate in northern Ecuador and southern Colombia is unclear.

Right: Low-resolution (Copernicus 30 m) DTM shows potential southwest–northeast striking faults between the cities of Pasto and Ibarra.

Instrumental seismicity and these faults suggest distributed deformation across many structures.

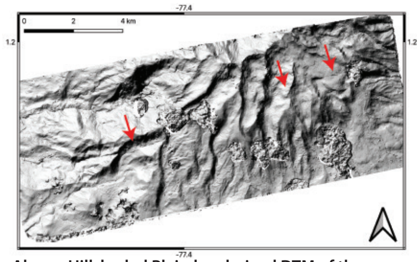
Geodetic block modelling suggest two major fault zones zones in the study area (red lines), both accommodating right-lateral deformation.

We requested Pleiades imagery (blue outlined areas) and have received and analyzed two sets of stereo-imagery to date.



Low-resolution hillshaded DTM with potentially active faults (dashed black lines) and geodetic block model boundaries (red lines). Block model boundaries from Jarrin et al., (2023). Seismicity catalogue consists of events between 1993 to 2016 from the IG-EPN catalogue available at https://www.igepn.edu.ec/catalogos-sismicos.

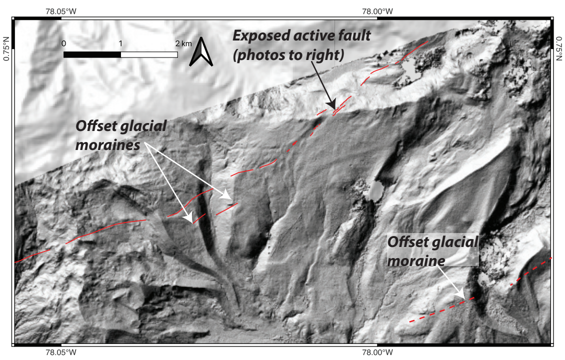
INSET B



Above: Hillshaded Pleiades-derived DTM of the southern flank of Galeras volcano shows laterally offset glacial moraines (likely 20–18 ka, Schubert & Clapperton, 1990).

These are likely part of a right-lateral fault system that strikes through the city of Pasto (Tibaldi & Leon, 2000; Rovida & Tibaldi, 2005).

INSET A

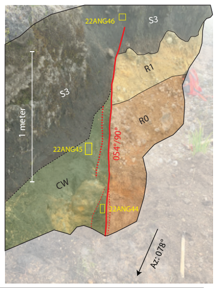


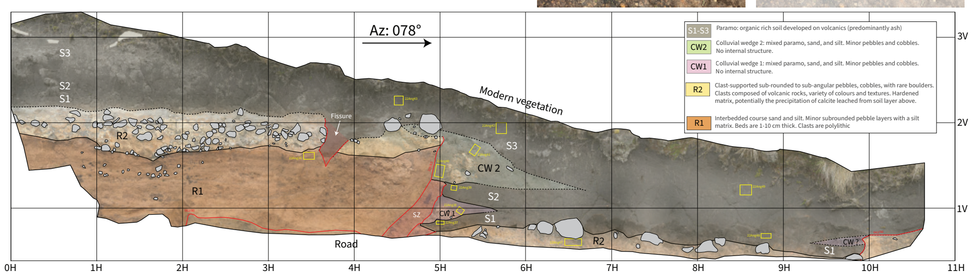
Above: Hillshaded Pleiades-derived DTM of active fault zone cross-cutting and deforming glacial moraines from ~13–10 ka (thus deformation is post glacial (Holocene).

Right and below: Field mapping of exposed active faults (from inset A) that offset dark, organic-rich, volcanic soil.

Bottom image shows two colluvial wedges (CW1 and CW2), which formed immediately after surface rupturing earthquakes, thus we interpret two earthquakes are recorded in the stratigraphy.

Radiocarbon dating of samples (yellow boxes), will constrain the timing of the earthquakes.





Problems

Consistent cloud cover resulted no Pleaides images for 2 years.

Another method that can penetrate cloud cover may be more viable for mapping faults in this climate (e.g. SAR-based DTMs).

Abundant vegetation requires methods that can penetrate to ground surface.

Abundant cloud cover in the high alpine plateau of El Angel, Ecuador.

Conclusions

We were able to use Pleiades to delineate active structures in the northern Andes, despite the vegetation and cloud coverage.

However, the persistent cloud cover hampered our ability to receive the data before our field mission; other methods may be better suited for generating DTMs in this region.

Our study shows that a ~100 km wide zone of distributed right-lateral faulting occurs in northern Ecaudor and southern Colombia.

These fault have hosted large (likely M > 6), surface-rupturing earthquakes, and should be considered in regional PSHA models.

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