

# The Physical Geography of Eastern Taiwan as a Baseline for Tourism and Earthquake Hazards

Rebecca Reinbold<sup>1</sup> & Martin Mitchell<sup>2</sup>

<sup>1</sup> Hydro-analyst; Elevation-Derived Hydrography, Minnesota State University, Mankato, USA

<sup>2</sup> Professor of Geography, Department of Anthropology & Geography, Minnesota State University, Mankato, USA

Correspondence: Martin Mitchell, Professor of Geography, Department of Anthropology & Geography, Minnesota State University, Mankato, USA.

Received: April 5, 2024

Accepted: May 28, 2024

Online Published: May 30, 2024

doi: 10.5539/jgg.v16n1p31

URL: <https://doi.org/10.5539/jgg.v16n1p31>

## Abstract

The eastern region of Taiwan is underpinned by a complex tectonic setting that forms the basis for numerous landforms, such as the Coast Range, Longitudinal Valley and Central Range, along with a rocky shoreline punctuated by a series of scenic beaches. In many ways, this tectonic setting resembles that of the west coast of North America. Taiwan's climate ranges from tropical monsoon (Am) with periodic typhoons to temperate and even subalpine climates based on dramatic changes in altitude caused by the tectonic setting. This situation produces a host of different ecological zones based on vertical zonation. The physical setting, along with recent infrastructure improvements, forms a baseline for tourism. Moreover, comprehending the region's structural geology is crucial for understanding the region's risk of severe earthquakes, as exemplified by the recent 7.4 magnitude earthquake on April 2, 2024, near the east coast city of Hualien. Our methodology centers on a review of pertinent literature and field reconnaissance conducted in 2014, 2016, 2019, 2020 and 2024.

**Keywords:** plate tectonics, earthquakes, Taroko Gorge, Longitudinal Valley, Coast and Central ranges, tourism

## 1. Tectonic Setting

Taiwan's tectonic setting is derived from the intersections between the Luzon Volcanic Arc of the Philippine Sea Plate, the Eurasian Continental Plate and the Okinawa Platelet located north of Hualien. The Luzon Arc includes Green Island, which is located approximately 10 km (6 miles) offshore of Taitung in southeastern Taiwan (Figure 1a).



Figure 1a. Looking east toward Green Island, part of the Luzon Volcanic Arc

This complex setting features the westward movement of the Philippine Sea Plate with its subduction underneath the Okinawa Platelet (a minor continental tectonic plate located in northeastern Taiwan) and the Eurasian Plate's subduction along a contact zone extending seaward from Taroko Gorge; as shown in Figures 1b and 1c. Moreover, the Philippine Sea Plate intersects southeastern Taiwan at an oblique angle and overrides the Eurasian continental plate, a somewhat unusual situation in the realm of plate tectonics. According to Stein et al. (2024), the subduction rate of approximately 90 mm/year for the Eurasian Plate is more than double the rate of subduction occurring off the coast of Oregon and Washington, where the Juan de Fuca plate subducts under the North American plate. Further south, the Eurasian plate continues to subduct underneath the Philippine Sea plate (Figure 1b).

As these plates collide, faults form with varying degrees of vertical and horizontal movement, and earthquakes often occur. A contemporary example is the recent 7.4 magnitude earthquake that occurred at 8 am on April 2, 2024, with an epicenter located 18 km (11 mi) south-southwest of Hualien that was followed 13 minutes later by a 6.5 magnitude aftershock (Figure 1d) (USGS 2024). Indeed, over the past 50 years, seven earthquakes registering over 7.0 on Richter's scale have occurred, including a 7.7 magnitude in September of 1999 that resulted in nearly 3,000 deaths and over \$14 billion USD in property and infrastructure damage (USGS 2024). In contrast, on April 2, 2024, the earthquake resulted in only 9 deaths because of stricter building codes and a robust emergency response system (Kuo et al. 2024).

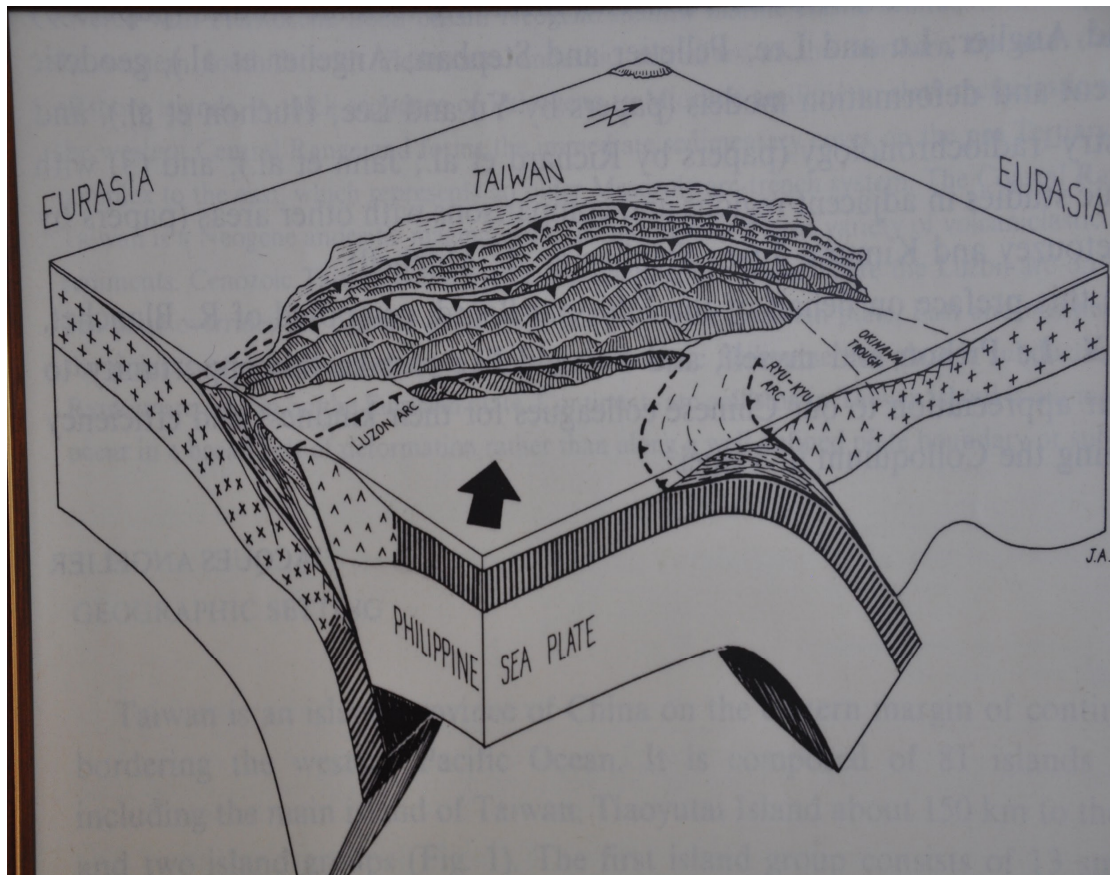


Figure 1b. Block diagram from the Southern Geology Museum of Taiwan depicting the tectonic cross-sections of the Philippine Sea Plate, Okinawa Platelet and the Eurasian Continental Plate

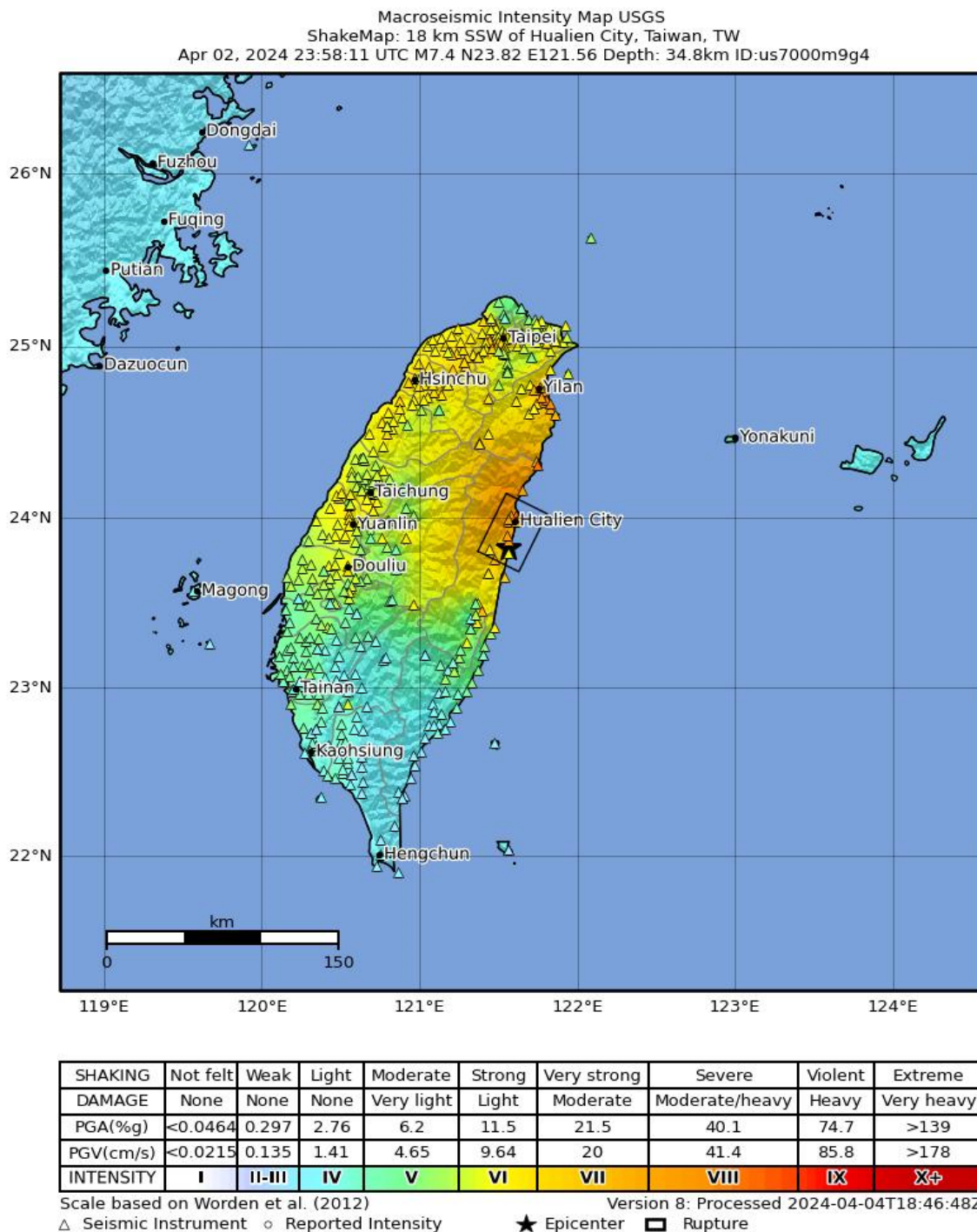


Figure 1c. U.S. Geological Survey Earthquake Intensity Map

The boundary between The Philippine Sea Plate and the Okinawa platelet is located immediately north of the 24<sup>th</sup> parallel with Taroko Gorge located onshore at the same location.

### 1.1 Landforms

The Coastal and Central Ranges of Taiwan result from these colliding plates. Metamorphism increases from west to east across the Taiwanese ranges due to the immense amount of compression from the Philippine Sea Plate. Huang et al. (2015) and Chang et al. (2023) indicated that the Central Range is rising at 1 cm/year and that much of the past orogenic activity occurred between 1.5-1.3 My and 300 Ka, while uplift rates for the Coast Range are more muted and range from 2 mm/year in the south to 5 mm/year in the north. Indeed, the

metamorphosed marble formations at Taroko Gorge depicted in Figure 2a, with their compressed and contorted appearance derived from this tectonic setting, combined with a distinct series of ecological zones (discussed later), form an important baseline for its national park status and its role as a magnet for tourism.



Figure 2a. Exposed Marble at Taroko National Park

Note the tone of the water that carries dissolved loads borne by active fluvial incision.



Figure 2b. Sharp dips in the sedimentary strata of the Coast Range with the strike aimed north toward the subduction zone with the Okinawa Platelet offshore of Hualien north of the 24<sup>th</sup> Parallel (see Fig. 1c)

The coastal mountain belt mostly grows by accretion associated with the collision of the Eurasian and Philippine Sea Plates (Figure 2b). The zone of attachment or suture zone usually contains a major fault. In Taiwan, the suture zone occurs in the Longitudinal Valley, as shown in Figure 2c, and is dominated by a left-lateral

strike-slip fault extending north/south along the interior or western base of the Coastal Mountain Range. Several other faults branch off this left lateral fault, creating a family of faults possessing varying amounts of vertical offsets (thrust faults) and horizontal offsets (lateral faults), a situation mimicking the San Andreas fault zone in western North America. Indeed, the left-lateral fault controls the orientation of the trunk streams in a similar manner to how San Andreas controls the orientation of the Salinas River in California.



Figure 2c. Photo depicting the Longitudinal Valley created by the left lateral fault resulting from the collision of the Philippine Sea Plate and the Eurasian Plate

Brown (2012) divided Taiwan's mountains into four north–south tectonic zones separated by faults. Starting from west to east, these are the: (1) Western Foothills, (2) Hsuehane Range, (3) Central Range, and (4) Coastal Range. Located on the Asian side of the Taiwanese mountain belt, the Western Foothills contain strike-slip faults and consist of Eocene and Miocene clastic sediments (Brown 2012). The Hsuehane Range features similar faults, and rocks dating from the Eocene and Oligocene are common (Ramsey 2007).

The Central Range, with a maximum altitude of 3,860 m (13,500 ft) forms the backbone of Taiwan. Despite possessing a tropical and subtropical latitudinal location, occasional winter snowfalls occur. Maximum uplift rates occur in the northern part of the Central Range and decrease gradually to the south (Brown 2012). The metamorphic rocks, consisting of marble and schist, date from the late Mesozoic and early Paleozoic (Brown 2012).

Dominated by sandstone, mudstone and turbidites (sea bottom deposits formed by massive slope failures), the Coastal Range is composed of accreted segments of the Luzon Volcanic Arc and has a much lower crestline than the Central Range, with the highest peaks cresting at 1,680 m (5,500 ft) (Figure 3a). Alluvium from these slopes forms the basis for fertile soils found in the intervening valleys of the Coast Range; however, these same slopes are easily eroded by intense fluvial incision when natural vegetation is removed (Figures 2b and 3b).



Figure 3a. Coast Range of Eastern Taiwan



Figure 3b. An orchard and exposed slopes from fluvial incision

As noted, the Longitudinal Valley, which comprises a narrow tectonic suture zone between the Philippine Sea plate and the Eurasian continental margin, as shown in Figure 4, separates the Central Range and the Coastal Mountain Range. The east side of the Longitudinal Valley is fronted by a series of small hills consisting of *mélange* found along the western edge of the Coastal Range. The Longitudinal Valley is dominated by a left lateral strike/slip fault that, according to Shyu (2006) and Wang et al. (2024), moves approximately 20-30 mm/yr per year with recent slips of 1.4 m (4.6 ft) associated with earthquakes that occurred in 1951 and 2022 in the vicinity of Yuli.

This left lateral fault controls the drainage of the two main trunk streams, one of which flows north through approximately 2/3 of the valley, whereas the other flows south (Figure 5). Separated by a small interfluvium, these two trunk streams are suggestive of how the San Joaquin River is separated from the Tulare basin in California's Central Valley by a similar low interfluvium. Possessing alluvial soils, the Longitudinal Valley supports an

agricultural base of rice and sugarcane with limited amounts of tea grown on the slightly elevated *mélange* areas fronting the eastern margins and lower slopes of the Coastal Range (Figures 6a-d).

East of the Coast Range, a narrow coastal plain with numerous beaches fronts the Pacific Ocean. Suggestive of California's Highway 1, Taiwan's Coast Highway 11 follows the shoreline from Hualien to Taitung. Hot springs, surfing, indigenous cultural centers, and scenic drives constitute a baseline for a growing tourism industry. Indeed, infrastructure improvements such as a controlled access freeway from Taipei to Suao (about halfway to Hualien) and an electrified passenger train from Hualien to Tai-tung that runs through the Longitudinal Valley are recent examples that have in essence pulled the Eastern Scenic areas closer to the population centers in northern Taiwan. Other improvements include road and train services west of Taitung to Kaohsiung (located on the southwest coast), which has effectively pulled Taiwan's second largest city closer to these scenic areas along the southeastern coast and reinforced tourism.

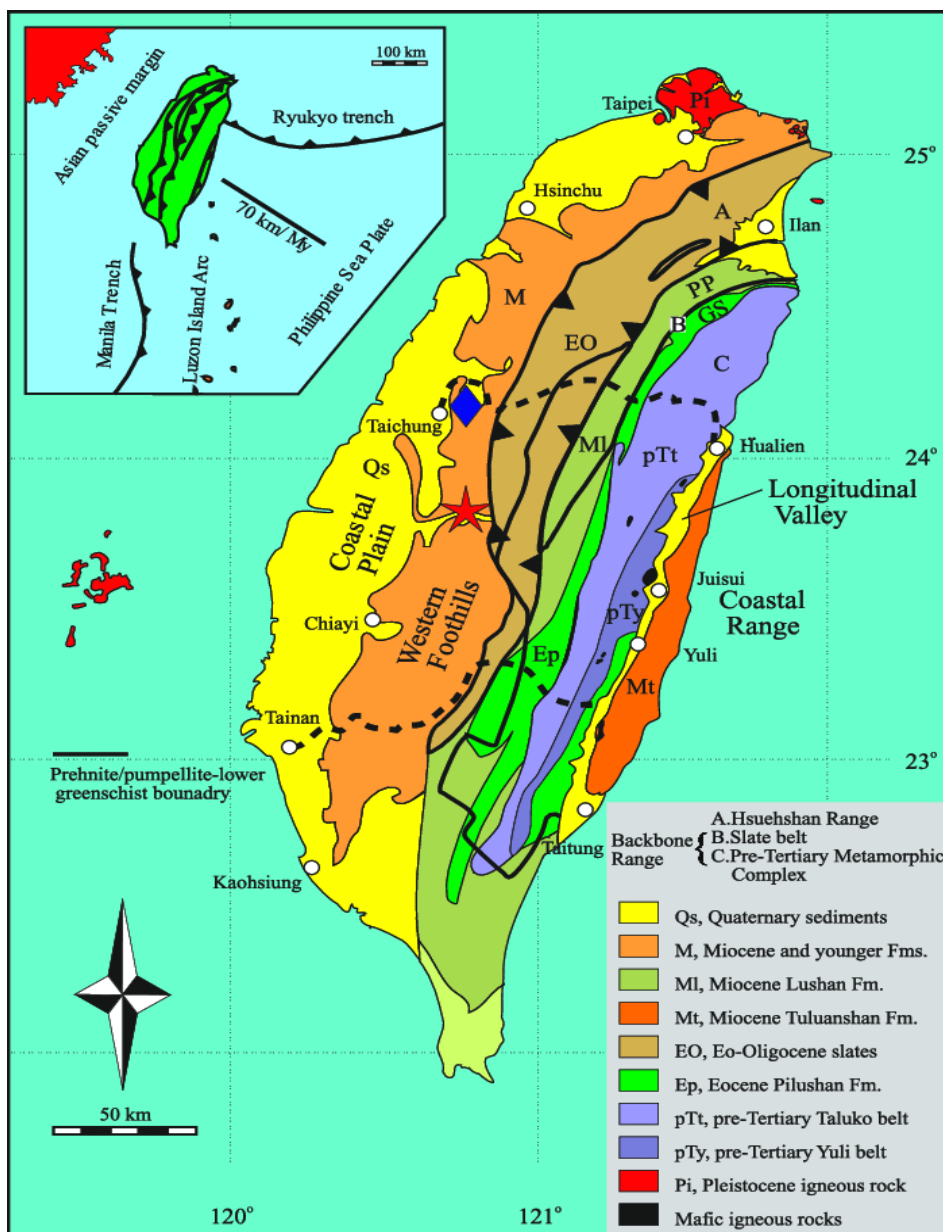


Figure 4. Map drawn by Pennsylvania State University showing the Western Foothills, the Central Range, Longitudinal Valley, and Coastal Range with relative rock ages



Figure 5. Trunk stream flowing north along the left-lateral strike-slip fault in the Longitudinal Valley  
Note the *mélange* and the Coast Range.



Figure 6a. Longitudinal Valley, planted with rice



Figure 6b. Longitudinal Valley: Sugarcane



Figure 6c. Tea on a slightly elevated mélange



Figure 6d. Rice in the Longitudinal Valley

## 2. Climate

The latitude, elevation, and seasonal shift in the East Asian Monsoon (EAM) are the main factors impacting Taiwan's climate. Straddling the Tropic of Cancer, 23.5°N, the island has a northern subtropical climate and southern tropical climate (Figure 7). Across the island at elevations below 610 m (2,000 feet), which corresponds to where the bulk of the island's population resides, hot and humid summers prevail with cool to mild winters. Because of more active frontal systems in the northern winter season, the northern zone receives the most annual precipitation, with Taipei averaging 2065 mm (81.3") per year compared to Taitung, which is located on the southeast coast, at 1,880 mm (74") per year (en-climate.org).



Figure 7. Photo taken by Graphic Maps, showing the Tropic of Cancer intersecting Taiwan

As noted, Taiwan is affected by the East Asian Monsoon (EAM), which is divided into warm and wet summers and cooler and drier winters. The summer version of the EAM starts in May and extends through October, with the wintertime version running from November through April (Dunn 1993). Considering a “sea-breeze” monsoon based on the differential heating rates between the land and ocean, the EAM during the summer

months features a high-pressure cell over the cooler ocean and a thermally driven low-pressure cell over the land because of more intense convective lifting (Tung 2020). Consequently, the pressure gradient extends inland with the prevailing winds blowing onshore, advecting the high dewpoints ( $> 70^{\circ}\text{F}/21^{\circ}\text{C}$ ) associated with the maritime tropical-unstable (mTu) air mass (Farnsworth 2019) (Figure 8).

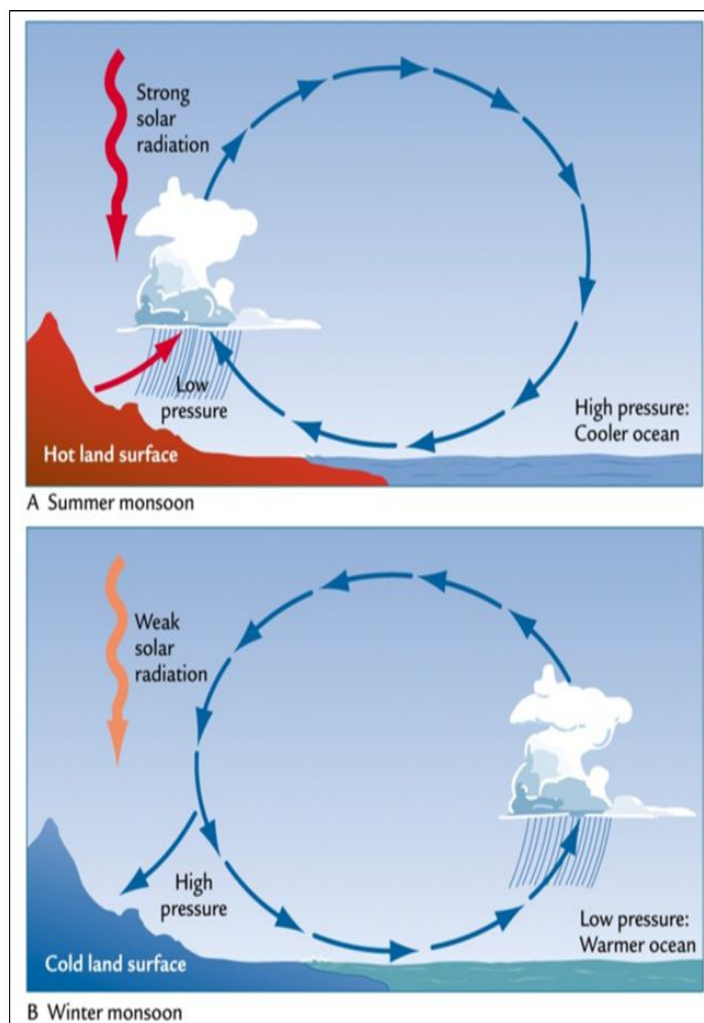


Figure 8. The formation of summer and winter monsoons

The typhoon season comprises another factor during the high-sun season (June through October), with Taiwan averaging approximately 3-4 typhoons per year (Wu and Kao 1999). When making landfall, typhoons often result in torrential rains because they are subjected to additional convective and orographic lifting. For example, from Taipei in the north through Taitung in the south, summer precipitation ranges from 1345 mm to 1475 mm (53" to 58"), which equates to 65% and 79% of the annual total, respectively (en-climate.org). Hualien is heavily impacted by typhoons in September, which forms the basis for its long-term average of 385 mm/15.2" of rainfall during September—the highest monthly total on the east coast.

The heavy high-sun season rains resulting from the EAM, especially when combined with a typhoon, result in flooding. Precipitation rates in eastern Taiwan are strongly influenced by the steep terrain of the Coastal and Central Ranges. The southwesterly winds and orographic lift associated with mountain ranges induce intense rainfall, and steep terrain exacerbates rapid runoff. Possessing wide channels that are braided most of the year because of the course of alluvium deposited by surges of runoff (both during and immediately after heavy rain events), their stream profiles resemble those of Saharan wadis or desert arroyos in the U.S. Southwest (Figure 9). Indeed, stream channels in the uplands are often choked with heavy boulders resulting from these episodic and intense bouts of heavy rainfall and consequent fluvial dissection (Figure 10).

The winter monsoon occurs from October to April and results in the prevailing middle latitude westerlies (Dunn 1993) (Figure 8). The winter monsoon is less powerful than its summer counterpart because of reduced surface

convection and the presence of more stable air masses originating over the Asian continent. Consequently, Taiwan experiences: (1) reduced precipitation and (2) an accentuated temperature gradient extending from south to north. For example, the winter version of the EAM results in only 405 mm (15.9") of precipitation in Taitung (21% of the annual total). However, further north in Hualien and Taipei, the winter EAM yields 600 mm (23.7") or 30% of the annual total and 720 mm (28.4") or 35% of the annual total, respectively, as middle latitude circulation regimes strengthen, and frontal lifting becomes somewhat more dominant as an offset to reduced surface convection.



Figure 9. Braided stream in the Longitudinal Valley, Central Range background



Figure 10. Boulders amidst a Coast Range stream (32 km/20 mi north of Taitung)

Southern Taiwan experiences a tropical climate zone (Koppen Am) with mild winters and hot-humid and rainy summers, driven by convective thunderstorms and punctuated by typhoons. South Taiwan is strongly influenced by the East Asian Monsoon (EAM) and receives nearly 80% of its annual precipitation during the summer season. The surrounding ocean, with its high sea surface temperatures, has a limited cooling effect along

the east coast during the high-sun season as the sea breezes move onshore. Moreover, this sea breeze has limited spatial impact because of the Coastal and Central Mountain ranges.

### 3. Ecological Zones

The climate and elevational changes in Taiwan, particularly given the mountainous nature of the topography, affect its ecosystems. Vertical zonation (a term used to describe how elevation substitutes for latitude) has a profound impact on this tropical setting. Moving upslope temperatures and absolute humidity decrease as precipitation increases. Indeed, as Box (2013) noted, Taiwan experiences two bioclimates: (1) warm tropical and temperate evergreen broad-leaved forests, also known as “Laurel Forests,” and (2) temperate deciduous forests with conifers, which are found in the humid uplands of mountain ranges.

Box and Fujiwara (2013) further divided Taiwan into six types of forests based on whether they are zonal or azonal. Box and Fujiwara (2013) reported that zonal forests are influenced by climatic factors, hence the role of elevation, while azonal forests are influenced by no climatic factors such as the hydrophytic soil conditions governing mangrove forests. Box and Fujiwara (2013) delineated the following vertical zones in Taiwan’s higher Central Range where the temperature decreases by approximately 6°C/km (11°F/3,300 ft): (1) tropical (sea level-900 m/3,000 ft), (2) subtropical (900 to 1525 m or 3,000-5,000 ft), (3) warm temperate (1,525-2,150 m or 5,000-7,000 ft), (4) temperate (2,150–2,750 m or 7,000-9,000 ft), (5) cool temperate (2,150 m-3,200 m or 9,000-10,500 ft) and (6) subalpine (3,200-3,965 m or 10,500-13,000 ft) zones (Figures 11 and 12).

Compared to the United States, a 3,200 m or 10,500 ft elevation on a Taiwanese mountain would equate to a similar climate and ecosystem in the Colorado Rockies at approximately 2,280 m (7,500 feet). Summertime temperatures at elevations of roughly 1,825 m (6,000 ft) mimic a pleasant spring day in upstate New York. Below 1,225 m or 4,000 ft (especially in the summer), the climate is suggestive of an August day in Florida with very warm temperatures and dew points averaging 21-27°C (70°-80°F). During winter, the highest peaks at nearly 3,960 m (13,000 ft) possess a modest and short-lived winter snowpack, suggestive of the southern Appalachians.



Figure 11. Entering the pine forest of Upper Taroko Gorge at 2,130 m (7,000 ft)



Figure 12. Timberline at the summit of Taroko Gorge 3,050 m (10,000 ft)

#### 4. Tourism

The eastern portion of Taiwan comprises a major tourist destination because of its geological diversity and complexity, as well as its numerous ecological zones with vertical zonation. For example, Taroko National Park received 2,440,000 visitors in 2021 (Taroko National Park, 2022). Its marble formations and distinct ecological or biological subregions based on vertical zonation are easily accessible by automobile or tour buses. Unfortunately, on April 2, 2024, an earthquake near Hualien caused several landslides and damaged many hiking trails along with important sections of Highway 8, which transects Taroko Gorge from near sea-level at Hualien to elevations greater than 3,050 m or 10,000 feet at the summit (Taroko National Park 2024). How quickly this damage can be mitigated remains to be determined.

Similarly, the East Coast Natural Area averaged more than 100,000 visitors per month in 2018, and the East Rift or Longitudinal Valley peaked at 608,000 in May 2018 (CEICdata.com 2024). Beaches, hot springs, and scenic drives over the Coast Range or along the Eastern shoreline form a set of tertiary economic activities tied to tourism. Warmer temperatures in the winter compared to those in northern Taiwan also result in a growing tourist trade, particularly in the Tai-tung area. An upgraded electric train operating at 135 km/h (85 mph) from Taipei to Taitung to Kaohsiung along with road improvements tying the East Coast and the Longitudinal Valley to the population centers of northern and southwestern Taiwan comprise examples of recent infrastructure projects that have made the eastern sections of the island more accessible. Aside from tourism, agriculture remains a mainstay activity in the Longitudinal Valley, and numerous small fishing harbors proliferate along the East Coast to round out primary economic activities.

#### 5. Conclusion

The physical setting on eastern Taiwan with its complex structural geology and plethora of vertical zones forms a physical base for drawing tourists, both domestic and foreign. Although, this tectonic setting results in a series of mountain ranges and intervening valleys and a spectacular cliff coast with a series of pristine beaches, it also forms the basis for periodic earthquakes, some of which can be quite strong as occurred in April 2024. Robust building codes limited human casualties. How quickly the road network can be repaired or rebuilt, particularly at Taroko Gorge, will be crucial for sustained tourism especially since recent infrastructural improvements have effectively pulled the East Coast region closer to Taiwan's major population centers.

## References

- Box, E. O., & Fujiwara, K. (2013). "Ecosystems of Asia," in *Encyclopedia of Bio Diversity, 1*. Retrieved from on 2/5/20 at <https://www.sciencedirect.com/science/article/pii/B978012384719500304X?via=ihub> doi.org/10.1016/B978-0-12-384719-5.00304-X
- Brown, D., Alvarez-Marron, J., Schimmel, M., Wu, Y.-M., & Camanni, G. (2012). "The Structure and Kinematics of the Central Taiwan Mountain Belt Derived from Geological and Seismicity Data," *Tectonics*, 31(5). <https://doi.org/10.1029/2012TC003156>
- CEICdata.com. (2024). *Taiwan: Number of Tourists 2024*. Accessed 4/11/2024 at: <https://www.ceicdata.com/en/taiwan/number-of-tourists-by-tourist-attractions/number-of-tourist-ns-east-rift-valley-ns>
- Chang, Q., Hren M., Lai L., Dorsey, R., & Byrne T. (2023). "Rapid Growth in Taiwan Orogen since 1.3-1.5 Ma" *Science Advances*, accessed 4/29/2024 at <https://doi.org/10.1126/sciadv.ade6415>
- Dunn, Margery G. (Editor). (1993). "Exploring Your World: The Adventure of Geography." Washington, D.C.: National Geographic Society
- En-climate.org. (2020). *Climate data for Taiwan* retrieved on 4/29/20 at <https://en.climate-data.org/asia/republic-of-china/hualien-city/hualien-city-1049/>
- Farnsworth, A. (2019). "The East Asian Monsoon Is Many Millions of Years Older Than We Thought," accessed 4/15/2020 at <https://theconversation.com/the-east-asian-monsoon-is-many-millions-of-years-older-than-we-thought-126141>
- Huang, C., Ouimet, W., Byrne T., Tung H., Chen Y.W., Kuo Y.P., & Hu, J.C. (2015). "Geomorphic Indices and Differential Uplift Patterns in the Southern Central Range of Taiwan," *American Geophysical Union*, accessed 4/29/2024 at <https://ui.adsabs.harvard.edu/abs/2015AGUFM.T53A..05H/abstract>
- Kuo, Lily, Pein-Lin, & Vic Chaing. (2024). "Huge Taiwan Quake Caused Few Deaths, Thanks to Preparedness and Luck," *Washington Post April 4, 2024*. Accessed 4/18/24 at <https://www.washingtonpost.com/world/2024/04/04/taiwan-earthquake-hualien-update/>
- Lin, Chao-chi, Rji-tun Chou, Tai-Wan-De-Di-Zhi, & Zhong-Yang-Yuh-Gan. (1974). *Geology of Taiwan*, 6-12, 109-118.
- Lin, C.-T., Li, C.-F., Zeleny, D., Chytry, M., Nakamura, Y., Chen, M.-Y., Chen, T.-Y., Hsia, Y.-J. Hsieh, C.-F., Liu, H.-Y., Wang, J.-C., Yang, S.-Z., Yeh, C.-L., & Chiou, C.-R. (2012). "Classification of High-Mountain Coniferous Forests in Taiwan." *Folia Geobotanical*, 47, 373-401. <https://doi.org/10.1007/s12224-012-9128-y>
- Petley, Dave. (2024). *Landslide in Taroko Gorge from the April 3, 2024 Earthquake*. Accessed 4/11/2024 at: <https://eos.org/thelandslideblog/taiwan-earthquake-2>
- Ramsey, L. A., Walker, R. T., & Jackson, J. (2007). Geomorphic Constraints on the Active Tectonics of Southern Taiwan. *Geophysical Journal International*, 170(3), 1357-1372. <https://doi.org/10.1111/j.1365-246X.2007.03444.x>
- Shyu, J. B. H., Sieh, K., Avouac, J.-P., Chen, W.-S., & Chen, Y.-G. (2006). Millennial slip rate of the Longitudinal Valley fault from river terraces: Implications for convergence across the active suture of eastern Taiwan. *Journal of Geophysical Research*, 111(B8). <https://doi.org/10.1029/2005JB003971>
- Stein, R.S., Toda, S., Chan, C.-H., & Sevilgen, V. (2024). "Magnitude 7.4 shock ruptures a fault in the Longitudinal Valley of eastern Taiwan," *Temblor*, accessed 4/29/2024 at <https://temblor.net/temblor/magnitude-7-point-4-shock-ruptures-longitudinal-valley-fault-taiwan-16055/>
- Taroko National Park. (2022). *Policy Statement 2022*. Accessed on 4/10/2023 at: <https://www.taroko.gov.tw/en/cp.aspx?n=7890>
- Tung, Y. S., Wang, S. Y. S., Chu, J. L., Wu, C. H., Chen, Y. M., Cheng, C. T., & Lin, L. Y. (2020). "Projected Increase of the East Asian Summer Monsoon (Meiyu) in Taiwan by Climate Models with Variable Performance," *Meteorological Applications*, 27(1). <https://doi.org/10.1002/met.1886>

- U.S. Geological Survey. (2024). *Tectonic Summary*. Accessed on 4/12/24 at: <https://earthquake.usgs.gov/earthquakes/eventpage/pt24094050/executive>
- Wang, Y., Wu, S., & Li, Y.Y. (2024). “*Surface Ruptures of the 2022 Guanshan-Chihsang Earthquakes in the Longitudinal Valley Raea, eastern Taiwan*,” National Taiwan University, accessed 4/29/2024 at <https://doi.org/10.21203/rs.3.rs-3825335/v1>
- Wu, C, & Y. Kao. (1999). “Typhoons Affecting Taiwan: Current Understanding and Future Challenges,” *Bulletin American Meteorological Society* at <https://journals.ametsoc.org/doi/pdf/10.1175/1520-0477%281999%29080%3C0067%3ATATCUA%3E2.0.CO%3B2>

### Copyrights

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (<http://creativecommons.org/licenses/by/4.0/>).