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# The Tertiary Piedmont Basin and Its Comparison with Arc-Continent Collision Basins

Aron Agona

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Department of Geological Sciences
Stockholm University
SE-106 91 Stockholm

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# Abstract

The Tertiary Piedmont Basin (TPB) in northwest Italy formed between the Western Alps and the Northern Apennines during a time of active tectonics. This study examines how the TPB developed and tests whether its evolution is similar to a modern arc–continent collision basin such as Taiwan. Using published geological maps, stratigraphic data, facies descriptions, and thermochronology, the results show that the TPB was shaped by repeated phases of uplift and subsidence caused by Alpine back-thrusting, Apennine slab rollback, and later extension. Its sedimentary record includes deep-marine turbidites, slope-failure deposits, evaporites, and shallow-water units. Thermochronology indicates unusually high heat flow linked to mantle upwelling.

Comparison with Taiwan shows that both basins experienced rapid tectonic changes, mixed compression and extension, and unstable basin slopes. However, the TPB formed over a much longer time and is better preserved, while Taiwan is still actively deforming. Overall, the TPB can be seen as a hybrid basin that records the full transition from collision to post-collisional extension, similar in process but longer-lived than Taiwan.

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# The Tertiary Piedmont Basin and Its Comparison with Arc-Continent Collision Basins

## 1. Introduction

Sedimentary basins act as natural recorders of how the Earth's crust is in motion, deformed, and changes with time. Sedimentary basins require space for sediment accumulation. This space is generated mainly through tectonic forces that bring about the descent or bending of the Earth's crust. Climate, sediment supply, or changes in sea level determine what type of sediment fills this space.

Basin classification is often grouped into types such as foreland basin, subduction-related basin, strike-slip basin, and rift basin. In reality there can be transitions between basin types (Fig. 1). For instance, a basin can develop in front of a mountain belt (known as a foreland basin) or behind a mountain belt (known as a retro-foreland or wedge top basin) and either of these may transition during subsequent collision or extension into another type of basin.

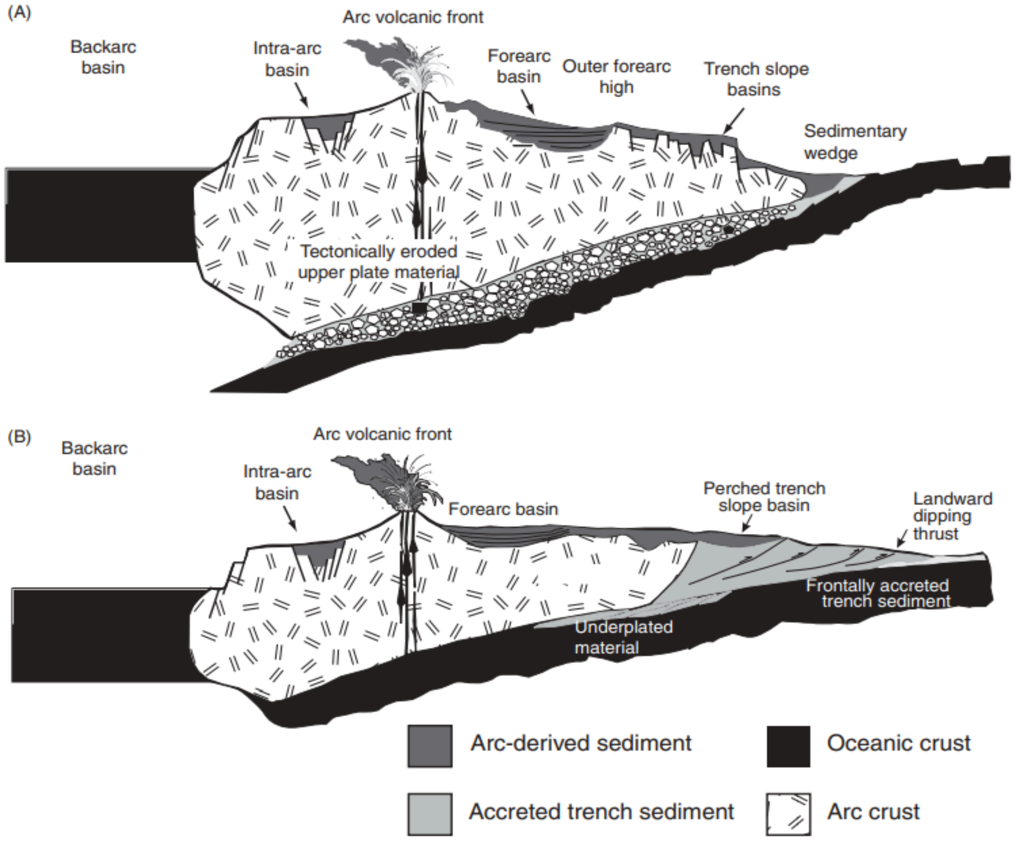

**Figure 1.** Classification of sedimentary basins according to tectonic setting (rift, foreland, back-arc, strike-slip, and hybrid types). Transitional basins like the Tertiary Piedmont Basin occupy an intermediate position between collisional and extensional regimes (from Busby, 2012).

A typical example of such a complex basin is the Tertiary Piedmont Basin (TPB) in northwestern Italy (Fig. 2). It is located exactly at the intersection of the Western Alps and the Northern Apennines. These are two mountain ranges formed from opposite collisional directions. The TPB basin is Oligocene to Miocene in age and is classified as a hybrid episutural basin (Maino et al., 2013).Episutural basins form along continental sutures and are associated with subduction zones that result in continental collision. The TPB is considered a hybrid basin because it combines the characters of both foreland and back-arc basin types.

This thesis examines the origins and development of the TPB. It then compares the TPB to basins formed in arc-continent collision zones, such as Taiwan. By such comparisons it is possible to learn how processes such as mountain building, subduction, and subsequent extensional faulting of the lithosphere influence basin formation and evolution.

**Figure2.** Location of the Tertiary Piedmont Basin (TPB) at the junction between the Western Alps and the Northern Apennines (modified from Maino et al., 2013). Abbreviations: LN – Langhe area, TPB – Tertiary Piedmont Basin,ADRIA – Adriatic microplate, SA – Sardinia,and CO – Corsica (Maino et al., 2013).

# 2. Background

## 2.1 Basin Formation and Tectonic Setting

The TPB is situated in a highly complex tectonic setting between the convergence of the European and Adriatic plates. The Western Alps were migrating to the east and the Apennine chain to the west (Turco et al., 2013).Thus, there was an area of overlap that resulted in pressure and extension of the crust in the TPB area.

It can be seen in early research (Carrapa & García-Castellanos, 2005; Maino et al., 2013) that the back-thrusting associated with the Western Alps led to the arching of the crust and the subsequent creation of a depression in which sediment accumulated. Afterward during the Miocene extensional faulting occurred due to the motion and rotation of the Apennine belt.

This complex setting resulted in the TPB recording both compressional mountain building and extensional rift events. The TPB’s evolution also fits into the larger story of the Mediterranean region, where the Corsica–Sardinia block rotated and slab rollback in the Apennines influenced the overall tectonic regime (Turco et al., 2013).

## 2.2 Types of Sediments

Sediments from the TPB contain evidence for depositional settings varying from deep-water, low-energy environments to high energy gravity flows (Mutti et al., 2002; Felletti, 2002). Such variations in depositional environment are illustrated in Figure 3 and show the two major sediment types commonly found in the basin.

**Figure 3.** Examples of sediment types in the TPB, showing the fine grained hemipelagic marlstones overlain by a coarse megabed (Key bed A) representing a high energy turbidite (from Di Giulio & Galbiati, 1993, their Fig. 4).

The lower section in the outcrop represents hemipelagic marlstones, which reflects low-energy deposition in deep water. Key-bed A, on the other hand, is represented by a coarse megabed formed in a higher energy environment; this rapidly deposited turbidity flow probably resulted from gravitational forces due to a steeper slope. The sharp change from hemipelagic marlstone to Key-bed A indicates low- to high-energy depositional forces in environments like the TPB (from Di Giulio, Galbiati, 1993, Figure 3).

### 2.3 Classic marine turbidite sequence

Turbidites have a typical vertical profile, which is generated by the loss of energy in a sediment laden flow. These vertical profiles are represented by the Bouma Sequence, in which there is coarse massive sand at the base (A), progressing to successively finer layers with increasing complexity. Units B and C consist of laminated and ripple laminated sandstone, laid down in conditions of rapidly decreasing flow rate. Unit D is fine siltstone, representing slow deposition from suspension, while mudstone (unit E at the top) indicates the ultimate deposition of fine-grained material due to flow settling. It is this vertical profile, and its relationship to deep water sedimentation, that has applications for identifying deep water depositional environments in basins like TPB.

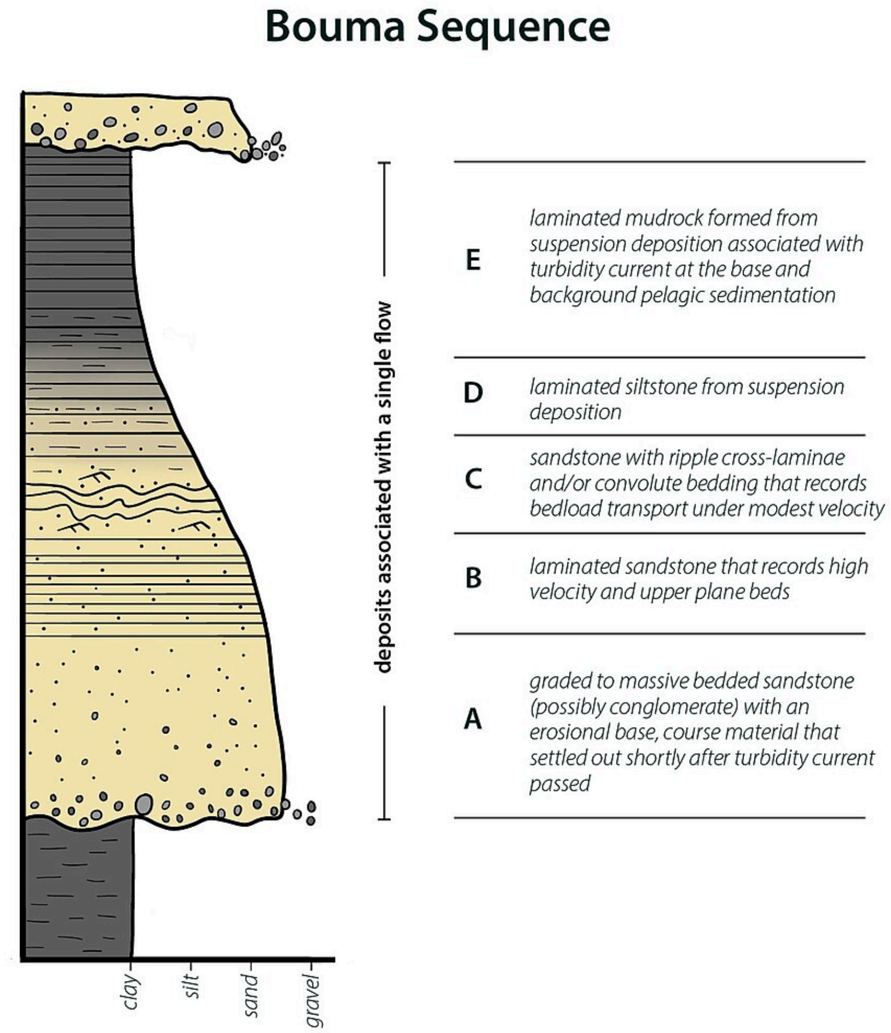

**Figure 4.** Classic Bouma turbidite sequence (A–E divisions) showing the characteristic vertical facies produced by a single turbidity current (from Bouma, 1962; image from Wikimedia Commons).

### 2.4 Geological Overview of the TPB

The TPB extends over the Langhe-Monferrato and Alessandria regions of Piedmont, Italy. Its sediment deposits date from Late Eocene to Late Miocene. A large proportion of the sediment is composed of marine turbidites that consist of sand and mud deposits formed as a result of gravity flows in a submarine setting (Mutti et al., 1995; Felletti, 2002). The basin's development happened in several stages (Maino et al., 2013):

- **Oligocene (Early Phase)**
  Flexural subsidence due to back-thrusting associated with the Alpine collision resulted in deep-water environments.

- **Miocene (Middle Phase)**
  The generation of normal faulting leading to localized subsidence and formation of new depocenters.

- **Late Miocene (Final Phase)**
  Compression occurred, reversing the earlier tectonic features uplifting crustal blocks.

### 2.5 Sedimentary Evolution

The TPB began as a deep basin that accumulated turbidites composed of sand and mud that were carried by density currents. As the basin shallowed, deposits of this material came to be topped by deposits of deltaic, coastal, and nearshore materials (Mutti et al., 2002). Tectonic activity resulted in several erosional unconformities and growth strata, which document sedimentation during faulting (Rossi, 2017; Ghibaudo et al., 2019).

Figure 5 shows how the main rock layers in the TPB were deposited from the Oligocene to the Messinian. It documents how the basin changed through time, from normal marine sedimentation to extreme drying and slope failure during the Messinian, and then back to open marine conditions. It also shows how these units change from west to east. At the base are the older marine sediments, followed by the Gessoso Solfifera Formation (GSF), which contains the gypsum formed during the Messinian Salinity Crisis. The Messinian Salinity Crisis occurred approximately 5.9 million years ago when the Mediterranean Sea nearly completely dried up. As a consequence, thick deposits of gypsum and evaporites were deposited. Some of these include the Primary Lower Gypsum (PLG) and the Resedimented Lower Gypsum (RLG) deposits in the vicinity of the River Alba (Dela Pierre et al., 2007). Above the gypsum deposits of the GSF, large fragmented rocks make up the Valle Versa Chaotic Complex (VVC), indicating steep basin slopes were unstable and sliding during this time. Higher up, the Lago-Mare deposits (LM) represent the stage when the Mediterranean became a shallow, brackish lake. The youngest layer shown is the Argille Azzurre Formation (AAF), marking the return to normal marine conditions in the early Pliocene.

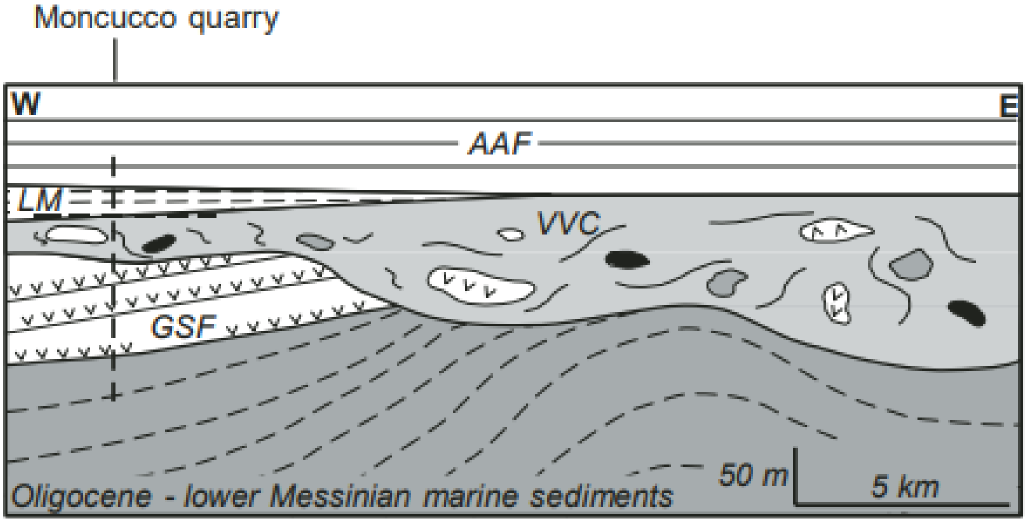

**Figure 5**. Sectional stratigraphy of the TPB with Oligo-Miocene deposits and evaporites of Messinian age (from Dela Pierre et al., 2007). AAF, Argille Azzuree Formation; GSF, Gessoso Solfifera Formation; LM, Lago-Mare; VVC, Valle Versa Chaotic Complex.

# 3. Methods

This study combines information from published fieldwork, geological mapping, stratigraphy, facies analysis, and structural interpretation to understand how the TPB formed and evolved. The methods described below explain how researchers have approached the basin, and how these techniques support the interpretations made in this thesis.

### 3.1 Fieldwork and Mapping

This research is aided by the work done in the field as well as the geological mapping, which provide direct evidence in the form of exposure in the TPB. In the geological maps, it becomes possible to distinguish the large faults, chaotic layers, evaporites, as well as unconformities, thereby enabling the determination of the basin configuration.

Figure 6 illustrates how outcrop-based mapping identifies key features of the TPB, including Units 1–3 of the chaotic complex, slope-failure deposits, and Lago-Mare facies. The combination of photos and interpretive sketches highlights the main faults, shear fabrics, and block geometries that characterize the Messinian evaporite system. Field photographs are important because they document structural and sedimentary relationships that are directly observed, and help us to visualize how tectonic activity influenced the basin's sedimentation.

### 3.2 Structural Interpretation

Structural interpretation assists the current research in detailing the influence of tectonics on the TPB over time. Through the consideration of the orientations of faults, the growth strata, as well as the variation in thickness, it is possible to trace the Alpine back-thrusting, basin flexure, as well as the Apennine transtensional stages of the TPB.

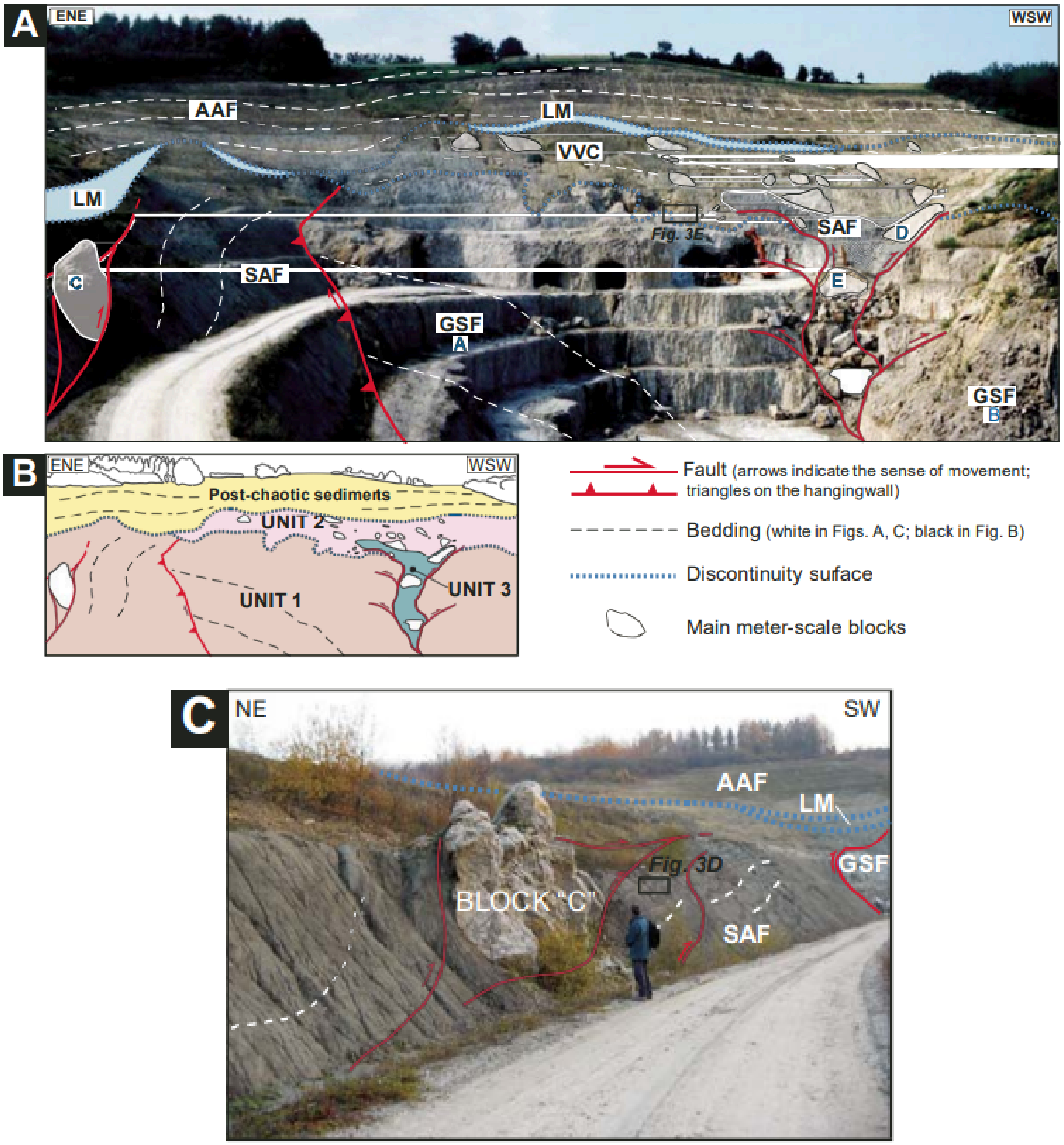

**Figure 6.** Field photographs, geological mapping, and structural interpretations from the Moncucco quarry, showing the relationships between gypsum units, chaotic blocks, faults, and bedding (from Dela Pierre et al., 2007).

The structural aspect of the work relies upon the data of Carrapa & García-Castellanos (2005), who explained the positive influence of the Alpine orogenic wedge upon the lithosphere, resulting in syn-sedimentary faults and the creation of accommodation space in the basin (Fig. 7). This demonstrates the importance of documenting the influence of deformational stages on the overall basin architecture.

### 3.3 Stratigraphic Analysis

Stratigraphy helps us understand how the TPB evolved by looking at the way sediment layers are arranged and how they change from place to place. By studying the vertical order of units and the transitions between them, it becomes clear when the basin was deep, when it became shallow, and when major events such as the Messinian Salinity Crisis occurred. Stratigraphic work also helps identify key marker beds and unconformities, making it easier to link changes in sedimentation to tectonic movements and/or sea-level fluctuations. This method provides the framework for understanding the TPB's overall geological history; the detailed stratigraphy is presented later in the Sedimentary Evolution section.

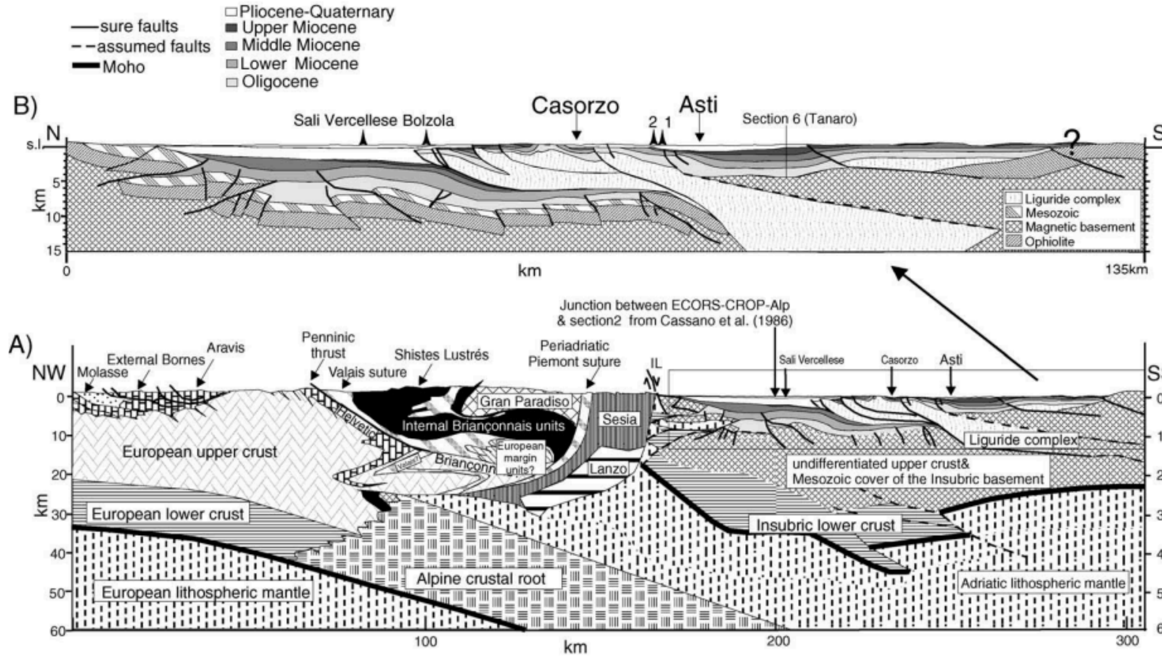

**Figure 7**. Crustal scale and basin scale cross sections across the Western Alps TPB and Apennine system (from Carrapa & García-Castellanos, 2005, their Fig. 2A–B). The diagrams show how the weight of the thickened Western Alpine wedge caused the lithosphere to flex downward, creating accommodation space for the TPB. (A) The deeper crustal section highlighting the Alpine root, major thrusts, and the transition toward the Apenninic domain. (B) The shallow crustal section illustrating the syn-sedimentary normal faults, growth strata, and the internal geometry of the basin.

### 3.4 Facies Analysis

Facies analysis shows the range of depositional environments preserved in the TPB, from deep-marine turbidites to evaporites and slope failure deposits (Fig. 8). The work of Felletti (2002) is particularly useful for understanding the geometry and internal structures of confined turbidites, which formed during the early deep-water stage of the basin. Studies such as Dela Pierre et al. (2007) also describe the characteristics of gypsum facies and chaotic deposits associated with slope instability during the Messinian. Together, these facies descriptions help interpret the processes that operated in the basin and how they changed through time. In figure 8, the paleogeographic map by Mutti et al. (1995; 2002) shows where deep water areas, slopes, shallow shelves, and sediment entry points were located. When all of this information is combined, it becomes easier to understand how the TPB evolved, how sediment moved, where it was deposited, and how tectonic changes controlled the depositional environment.

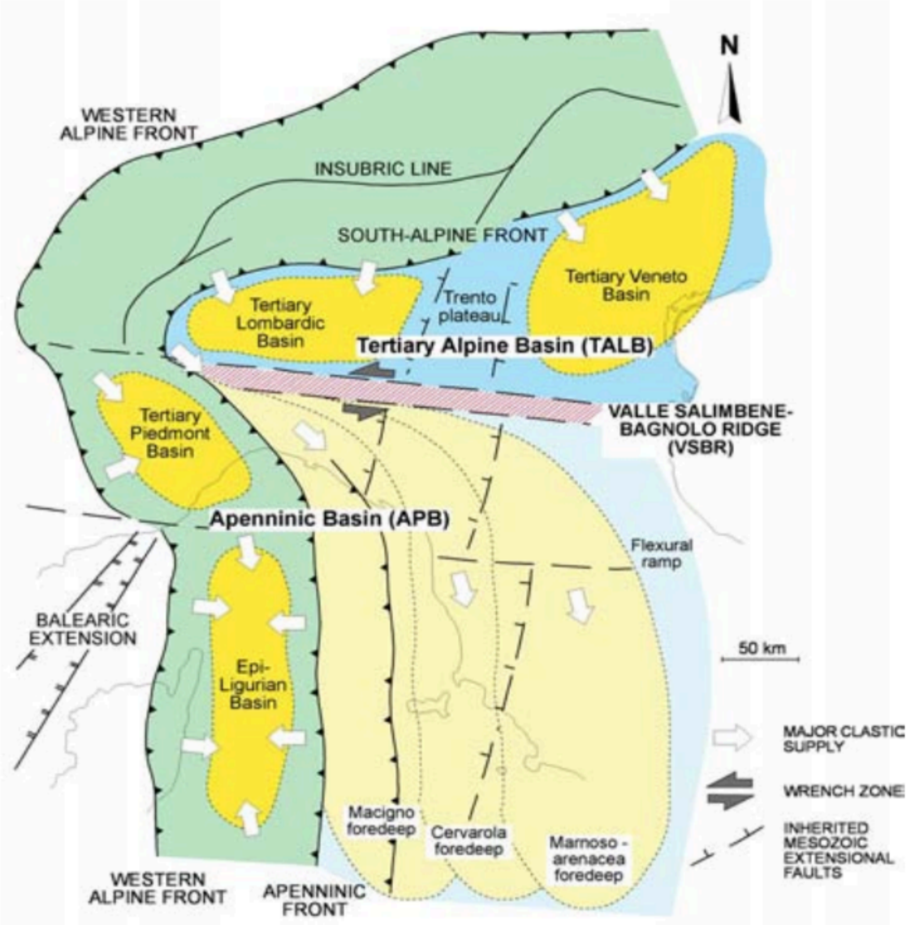

**Figure 8.** Simplified paleogeographic and facies map of the TPB and surrounding regions during the Oligocene Miocene. The map shows major depositional environments, including foredeep basins, shelf areas, clastic wedges, and basin depocentres, illustrating how sediment was routed into the TPB (after Mutti et al., 1995).

### 3.5 Regional Tectonic Framework

The tectonic setting helps to facilitate the research by placing the TPB within the context of the Alpine Apennine geodynamic setting. Maino et al. (2013) describe the tectono-sedimentary history of the basin in a series of figures illustrating the role of Alpine back-thrusting, Apennine slab rollback, and strike-slip faulting (Fig. 9). Figure 9 summarizes how the TPB evolved from the Oligocene to the Miocene under changing tectonic forces. The earliest stages show a basin strongly influenced by Alpine back-thrusting and flexural subsidence. Later stages (Chattian to Burdigalian) illustrate normal faulting, depocenter migration, and the increasing influence of Apennine slab rollback. Together, these explain why the TPB developed as a hybrid episutural basin shaped by both Alpine compression and later Apennine transtensional tectonic forces.

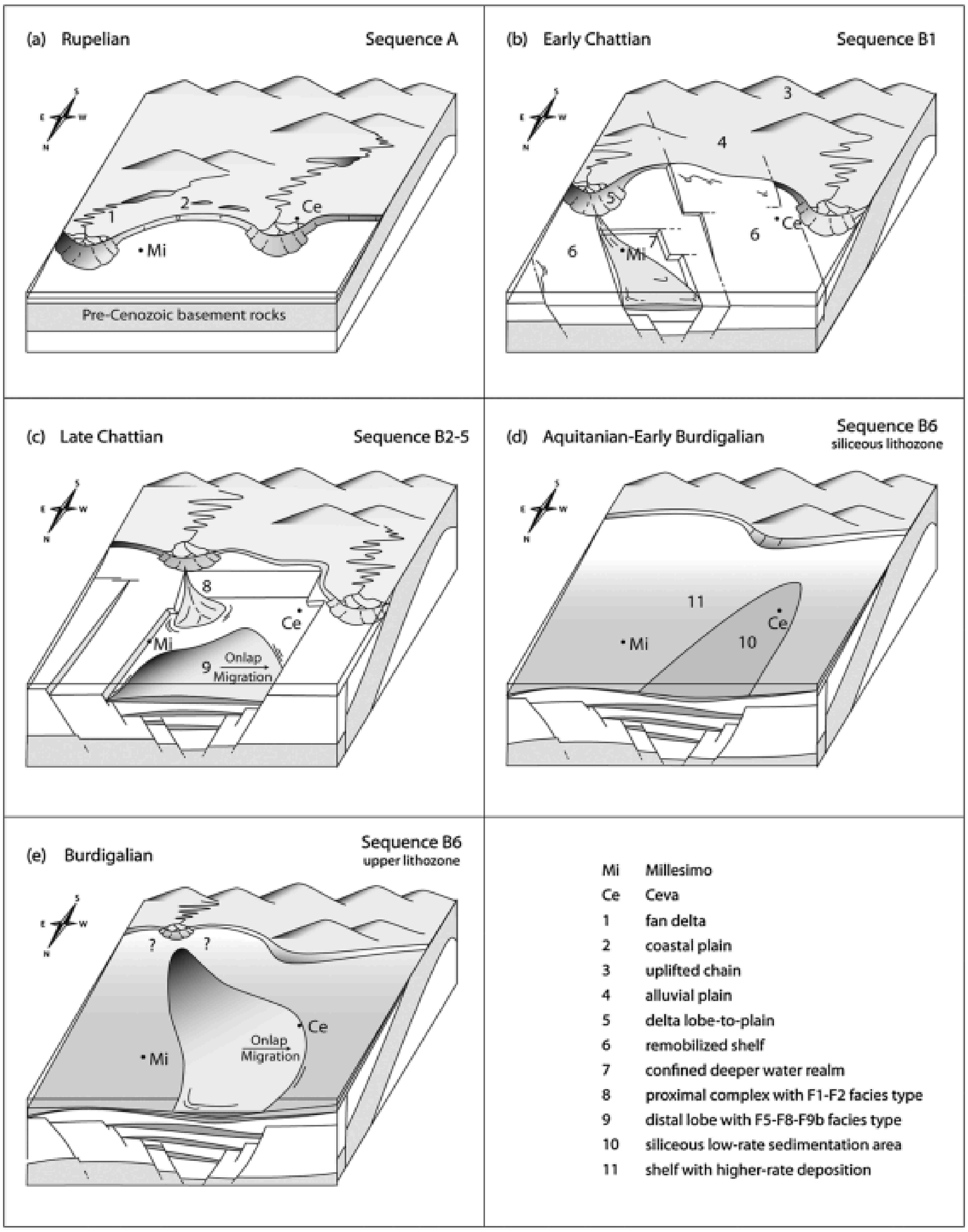

**Figure 9**. Multi stage tectono-sedimentary evolution of the TPB (from Maino et al., 2013).

# 4. Results

## 4.1 Tectonic Evolution

The TPB formed as the result of the bending of the crust beneath the weight of the Western Alps (Carrapa & García-Castellanos, 2005). Subsequently, the retreat of the Apennine subducting slab resulted in a change in the stress field with the formation of new normal and strike-slip faults.  This combination of compression, extensional, and strike-slip deformation formed the TPB into what is known as a hybrid episutural basin, a basin formed between two colliding mountain systems (Maino et al., 2013; Turco et al., 2013).

### 4.2 Regional Paleogeography and Facies Distribution

The TPB is situated at a network of interconnecting basins that are influenced by both Apennine and Alpine tectonics (Mutti et al., 2009; Maino et al., 2013) .The TPB occupied a transitional location between shallower foreland or slope settings, and deep-marine domains during the Oligocene–Miocene. The distribution of facies throughout the area demonstrates how uplift, subsidence, and shifting basin geometry frequently caused sediment routes to change. The TPB's wide variety of deep-water turbidites, slope deposits, chaotic mass transport units, evaporites, and near shore sediments can all be explained by this regional framework.

### 4.3 Stratigraphic Structure

The stratigraphic profile in Figure 10 (from Busby & Clift, 2011) provides a useful analogue for the early stages of the Tertiary Piedmont Basin. The lower part of the column is made up of thick, mud-rich and deformed deposits, representing material scraped off the down-going plate and added to an accretionary prism. Higher up, the succession becomes more organized, with repeated thin bedded sandstones and shales that record turbidite flows moving through a deep-marine setting. Air fall tuffs may also be deposited as thin layers, reflecting volcanic activity near this volcanic arc.

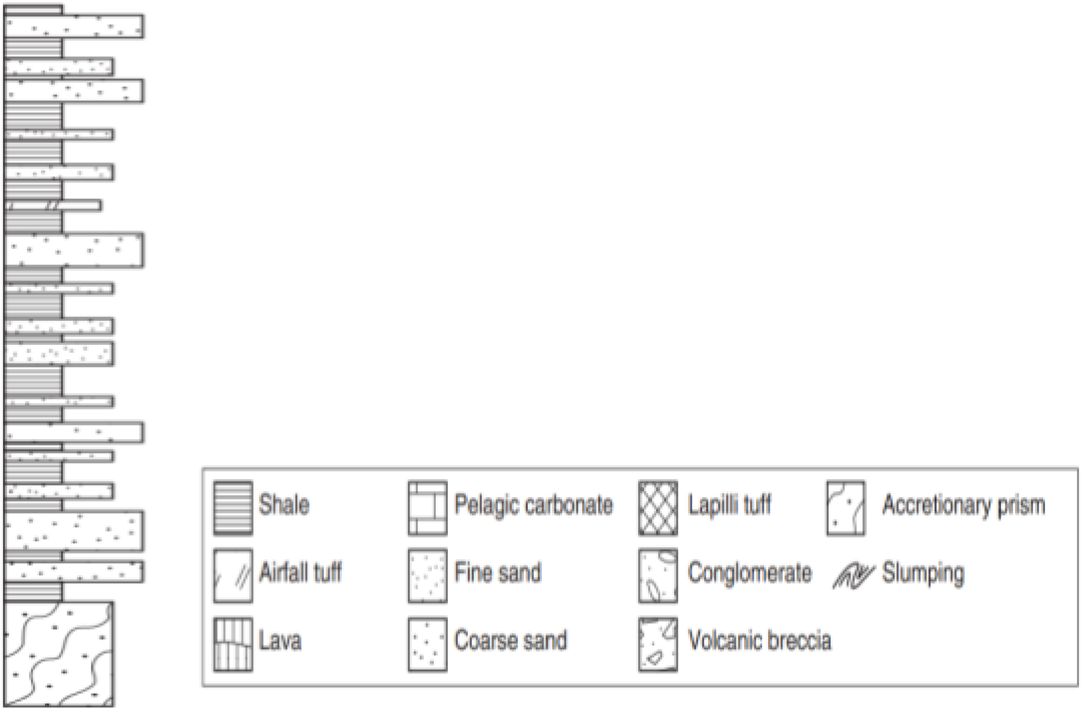

**Figure:10.** Stratigraphic profile of a forearc deep-water accretionary basin (from Busby & Clift, 2011).

This pattern of mud dominated, tectonically disturbed beds at the base, grading upward into more regular turbidites with interlayered ash layers, reflects a basin affected by both active deformation and sediment supply from a volcanic arc. These properties are quite similar to those found in lower TPB units, which also have deep-water turbidites, slumps, and document rapid variations in accommodation space caused by compression, uplift, and localized subsidence. Although the TPB later developed to become more mixed and shallower environments, its early stratigraphy aligns well with the forearc related deep-water system illustrated in Figure 10.

### 4.4 Thermal History

The thermochronology data of Amadori et al. (2023) indicates heating above 120-130 °C in the rocks at the bottom of the basin. This is too high to be attributed to simple burial at typical geotherms of c. 25°/km. It indicates that there is a high geothermal gradient of 45 °C/km due to upwelling of the mantle beneath the basin during the opening of the Liguro-Provençal Rift (Turco et al., 2013)and documents that the TPB is affected not only by deep earth processes (mantle upwelling) but also by shallower (plate bending) forces.

## 5. Discussion: Comparing the Tertiary Piedmont Basin (TPB) and Arc-Continent Collision Basins

The TPB shares many similar features with active arc-continent collisional basins, such as the Taiwan. Both are characterized by rapid tectonic cycles resulting in fast uplift and subsidence, leading to alternating deep and shallow marine deposits. Both the TPB and the Taiwan basin also show simultaneously compressive, extensional, and strike-slip faulting that results in complex structural elements and facies patterns. Despite sharing many similarities, the TPB and Taiwan are distinguishable in terms of their scale, degree of preservation, and/or stage of tectonic evolution.

The TPB took millions of years to evolve and preserves its entire stratigraphic sequence, while Taiwan is very young and active. Deformation is so rapid in Taiwan that many strata are folded or destroyed within a few years after formation. This proves that TPB depicts a late stage convergent margin environment, while Taiwan illustrates an early stage environment. Some of the similarities and differences are summarized in Table 1 below.

### 5.1 Stratigraphic Comparison

In order to understand the differences between these two basins, it is helpful to contrast the stratigraphic templates of both areas. The TPB is best represented by the accretionary profile from the forearc environment in deep water from Busby & Clift (2011) (Fig. 11), which shows a mix thin-bedded turbidites, mudstone, and deformation features associated with a tectonically uplifted environment in deep water. The early TPB environment corresponds to these conditions where turbidites in deeper water and chaotic deposits were formed as a result of changes in accommodation space (Fig. 10).

**Table 1.** Similarities and differences between the TPB and Taiwan

| Similarities | Tertiary Piedmont Basin (TPB) | Arc–Continent Collision Basin (Taiwan) |
|---|---|---|
| Influence of two converging systems | Alps (compression) and Apennines (extension) | LuzonArc and Eurasian plate |
| Rapid tectonics | Experience alternating compression and extension phases | Shift quickly between shortening and extension |
| Tectonic complexity | Combination of compression, extension and strike slip | Same forces applied |
| Mixed depositional environment | Contains deep marine turbidites and shallow water deposits | Also contains deep trenches, turbidites and shallow uplifted areas |
| Slope instability | Contains chaotic deposits, like Resedimented Lower Gypsum (RLG) and Valle Versa Chaotic Complex (VVC) | Contains major slumps deposits and deformed turbidites |

| Differences | Tertiary Piedmont Basin (TPB) | Arc–Continent Collision Basin (Taiwan) |
|---|---|---|
| Timescale | Long lived (tens of millions of years) | Very young and short lived (ongoing collision) |
| Heat flow origin | High heat due to post-collisional mantle upwelling | High heat from active crustal deformation |
| Tectonic stage | Represents a later, more mature stage in collision collapse | Represents an early, highly active collision stage |
| Preservation | Well preserved stratigraphy | Poor preservation due to rapid uplift and erosion |
| Stratigraphic style | More orderly and complete sequences | Highly disrupted, chaotic and frequently folded |

| | | |
|---|---|---|
| Structural stability | Relatively stable during later stages | Extremely unstable seafloor today |
| Basin type analogue | Matches figure 7(forearc deep-water accretionary) | Matches figure xx (trench-slope basin) |

The profile in figure 11 shows features such as mudstone intervals, slump sequences, chaotic zones, and disturbed turbidites. All these characteristics are typical of in areas where there is active collision. The stratigraphy of the Taiwan basin (Fig. 11) differs significantly from the TPB case (Fig. 10). The stratigraphy of Taiwan shows less order and greater disruption due to the rapid uplift and subsequent erosion caused by arc-to-continent collision.

**Figure 11**. Trench-slope basin stratigraphic column showing Taiwan’s active arc–continent collision environment (from Busby & Clift, 2011).

### 5.4 Taiwan Tectonic Cross Section

Figure 12 shows three cross-sections across northern, middle, and southern Taiwan and provides insight into how different areas of Taiwan are in different stages of tectonic activity (Busby & Clift, 2011). In this figure, northern Taiwan begins to break and sink due to extension, middle Taiwan experiences extreme collision and uplift, and southern Taiwan begins to undergo active subduction to form an accretionary wedge. The presence of all these processes occurring in one area makes Taiwan's geological complexity easier to explain and makes it a great study to learn from past TPB geological events. These comparisons demonstrate that the TPB is a later, more mature stage of convergent-margin evolution, with collision followed by extension and basin collapse. Taiwan, on the other hand, shows an early, extremely active stage, characterized by fast deformation and unstable sedimentation. This makes the TPB an important record of the entire tectonic "life cycle," from subduction to collision and post-collisional extension.

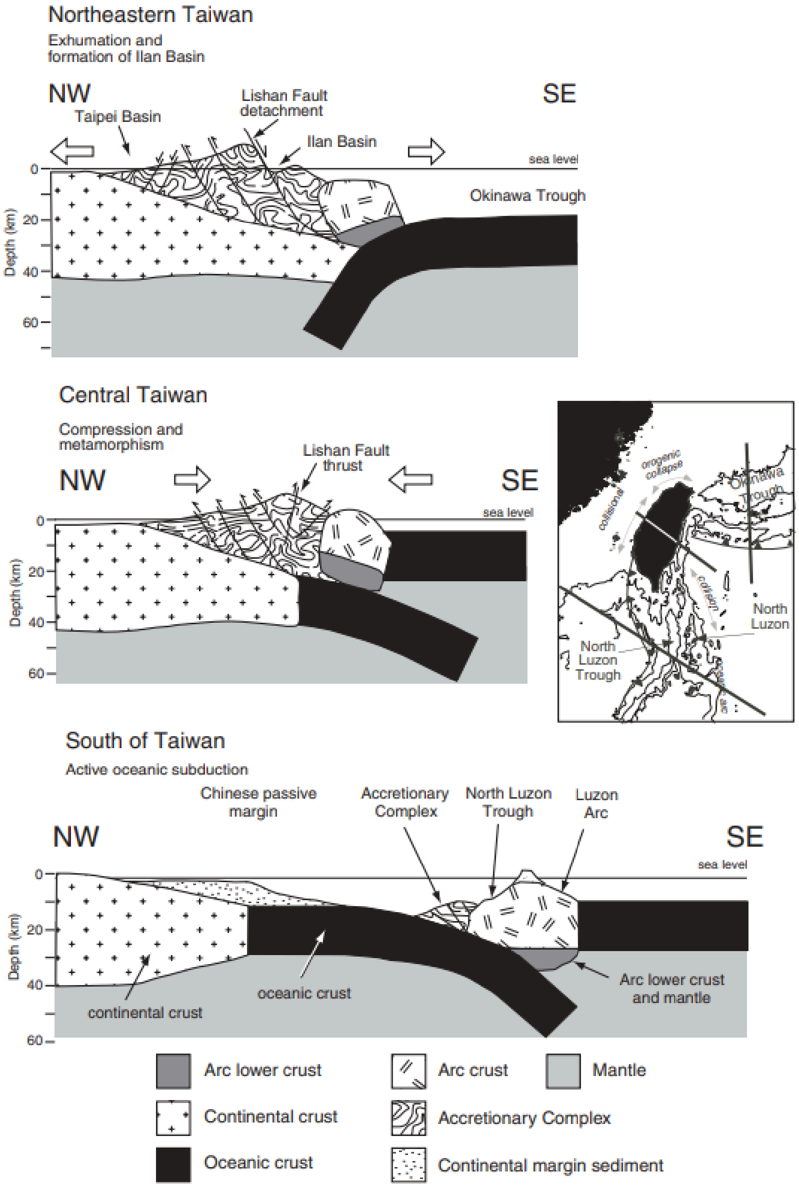

**Figure 12**. Tectonic cross sections through northern, central, and southern Taiwan showing simultaneous extension, collision, and subduction (from Busby & Clift, 2011).

## 6. Conclusions

The TPB resulted from Alpine back-thrusting followed by Apenninic extension, forming what is a hybrid basin, having been subject to both collision and extensional tectonics. Its sediment record preserves repeated cycles of subsidence, uplift, erosion, and shifting sediment pathways, showing how strongly tectonic forces controlled basin evolution. The high geothermal gradients recorded at depth point to the influence of mantle upwelling during the early stages of the Liguro Provençal back-arc opening.

When compared with modern arc continent collision basins such as Taiwan, the TPB shows similar rapid transitions between compression and extension, but over a much longer timescale. While Taiwan records these changes in real time due to active collision, the TPB preserves the entire cycle from collision to post-collisional collapse, making it an important example of how hybrid tectonic basins evolve through time.

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