STRATIGRAPHIC AND TECTONIC RE-ARRANGEMENT OF THE BASE OF THE ALBANIAN ALPS

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ABSTRACT

Traditionally, the tectonic basement of the Albanian Alps was considered to lie above the uppermost layers of the Cretaceous–Paleogene Cukali Shale Formation, recognized as the youngest unit within the Cukali Zone. However, recent findings have prompted a revision of this view, with a significant portion of the upper Cukali Shale now reinterpreted as dating from the Permian period. As a result, this section has been reclassified as part of the overlying "Sub-Pog Beds and Shale" unit, which is now regarded as the basal formation of the Albanian Alps. Ongoing research continues to refine the structural framework of the region. It has been determined that the Boks Formation dates to the Middle Triassic, which makes it younger than the structurally overlying Plan Formation, which spans the Early to Middle Triassic. This inversion in the expected stratigraphic sequence implies a complex tectonic history. The distinct facies of the contemporaneous Boks and Plan Formations suggest differing paleogeographic origins for the Albanian Alps and the underlying Sub-Pog Beds and Shale–Pog-Boks complex. This latter complex constitutes an independent unit, positioned structurally between the Albanian Alps (above) and the Cukali Zone (below). For purposes of regional correlation, it is essential to determine whether this newly identified unit between the Albanian Alps and the Cukali Zone represents a local feature or extends farther north, possibly occurring between the Budva Zone and the Hochkarst Nappe.

Keywords: Paleogeography; Western Tethys; Paleotethys; Adriatic Plate; Orogeny; Permian; Triassic; marine carbonates

1. INTRODUCTION

Figure 1 presents a map of northern Albania, a region of considerable importance for reconstructing the Permo-Triassic paleogeography of the western Tethys. Despite its significance, geological investigations in this area remain limited, aside from efforts focused on geological mapping and ore deposit exploration. The Albanian Alps are considered the southern extension of the Hochkarst Nappe, while the underlying Cukali Zone is regarded as the southern continuation of the Budva Zone. Research by Gaetani *et al.*, (2015) and Horaček *et al.*, (2023), building on earlier Albanian studies and incorporating new data, provides the first detailed and structured stratigraphic subdivision of the Albanian Alps. Our study continues this line of investigation, with a particular focus on the stratigraphy of the base of the Albanian Alps. The aim was to clarify the depositional age and sedimentary environment of formations spanning from the Permian to the Early–Middle Triassic. This task is complicated by several factors: the macroscopically unfossiliferous nature of the rocks, their significant thickness, regional-scale folding, and the widespread presence of previously overlooked olistostromal redeposits. Due to the inability to directly date the shale matrix—which in some areas exceeds 1000 meters in thickness—we instead focused on analysing limestone olistoliths embedded within these formations. Through micropaleontological analysis (foraminifera and conodonts), we were able to determine the ages of these clasts and, by extension, gain more coherent age constraints for the host formations. This investigation led to an unexpected finding: the Plan Formation is older than the structurally underlying Boks Formation, a result with significant stratigraphic and tectonic implications.

Localities

Investigating the region between Shkodra and Theth presents significant challenges. Within an area of approximately 50 square kilometres, there are only two main access routes: one follows the Kir River, and the other follows the Shala River. Both valleys trend roughly north–south and are connected by an east–west passage that begins in the village of Kir and extends across the Kir Pass toward the Shala Valley. Along these routes, we conducted two north–south transects: one along the Kir Valley between Plan and Kir, and the other along the Shala Valley from Breglumi (Nicaj Shala) to the Kir Pass (Figs. 2 and 3).

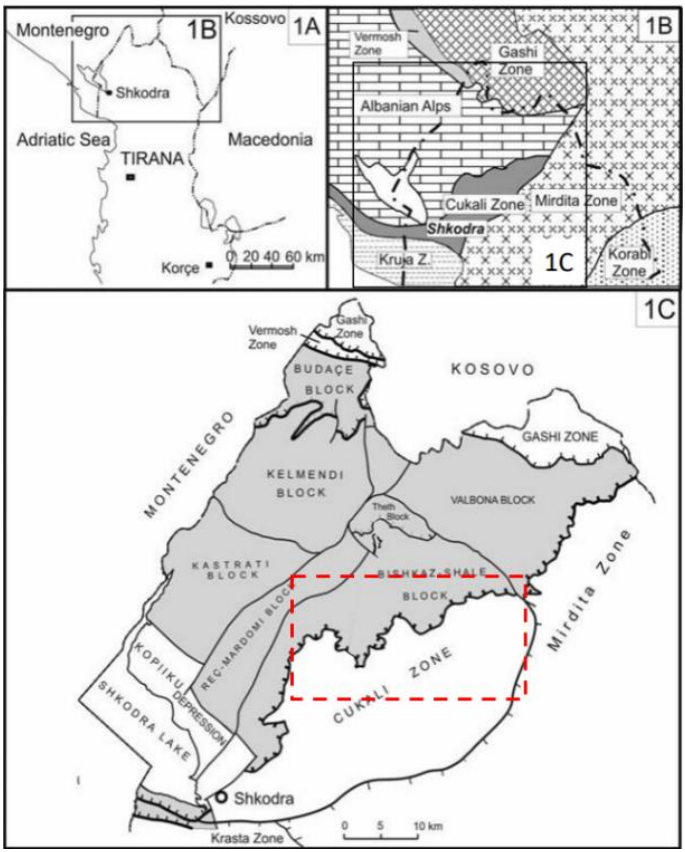

Fig. 1: Position of the research area after Gaetani et al. (2015) 1A and 1 B: Index map of the study area; 1A: Map of southeastern Europe; 1 B: Geologic zones; Z.=Zone. 1C: Structural map of the Albanian Alps. [Following Xhomo et al. (2008) and Gaetani et al. (2015), modified]. Despite that the different units are termed "Block" we regard them as "Sheet," see text. The red squares indicate the positions of the maps in Figs. 2 and 3.

Geological setting

The Albanian Alps are primarily composed of carbonate successions ranging from the Permian to the Jurassic in age (Gaetani *et al*., 2015) and are subdivided into several structural blocks or sheets (Fig. 1; see also Horaček *et al*., 2023). Of these, only the Bishkaz–Shale Sheet and the Theth Sheet are relevant to the present study. According to Gaetani *et al*.,

(2015), the base of the Albanian Alps is defined by the carbonates of the Pog Formation, although an underlying, as yet unstudied unit is also recognized (see next paragraph). The Pog Formation is overlain by the Boks Formation, which comprises shales interbedded with conglomerates and debris-flow deposits. Above this lies the Plan Formation, characterized by conglomerates, carbonates, and siliciclastic siltstones to sandstones.

However, Gaetani *et al.*, (2015), in their pioneering work—building on earlier Albanian studies (see references in Gaetani *et al.*, 2015, and Horaček *et al*., 2023)—noted that the very base of the Albanian Alps remained unstudied. This gap in knowledge has since been addressed by Horaček *et al.*, (2023; 2025), who presented the first results from this previously unexplored interval. Based on their findings, a revision of the existing structural division of the Albanian Alps has recently been proposed.

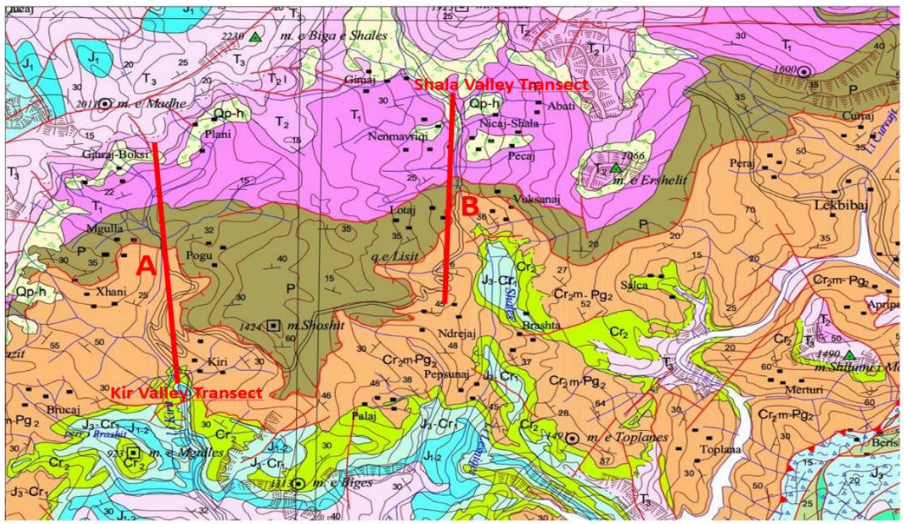

Fig. 2: Detail of the Geological Map of Albania by Xhomo *et al*., 2002, showing the base of the Albanian Alps (northern Albania), with the two transects indicated: A: Kir River (I. i. Kirit) transect, B: Shala (Shales) River transect.

It could be noted that in Figure 2**,** the boundary between the Cukali Zone (represented by the Cukali/Xhani Shale Formation, $Cr_2m–Pg_2$) and the Permian (P) deposits—specifically the Sub-Pog Beds and Shale—requires revision. This boundary should be shifted further south, reassigning a substantial portion of what was previously mapped as Cukali

Shale to the Sub-Pog Beds and Shale. Additionally, the legend symbol **T_1** (Lower Triassic), which currently represents both the Boks and Plan Formations collectively, needs to be revised. Modifications should reflect the correct extent and position of the Sub-Pog Beds and Shale – Pog–Boks complex**,** as well as an accurate delineation of the boundary between the Boks and Plan Formations. It is important to note that the Boks Formation is of Middle Triassic age, while the base of the Plan Formation belongs to the Lower Triassic, and the two are separated by a fault or thrust plane. For further detail on the extent and geometry of the Sub-Pog Beds and Shale – Pog–Boks complex, refer to Figure 3.

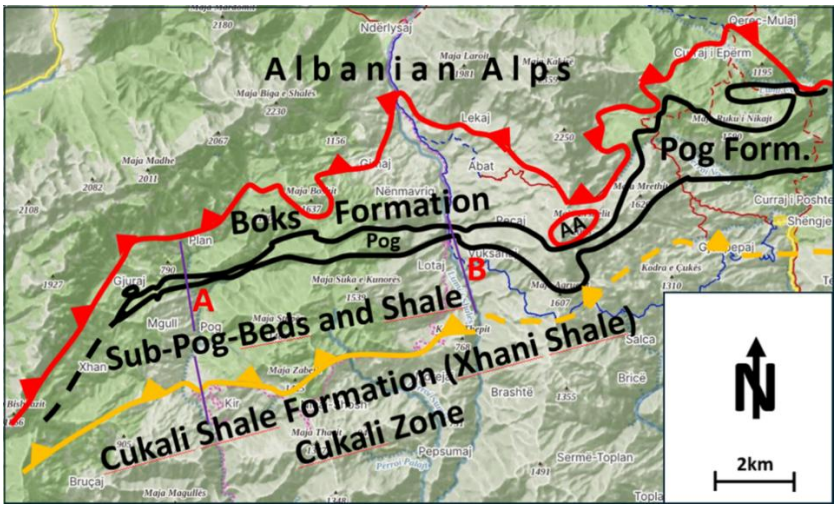

Fig. 3: Topographic map (from Google Maps, Google Inc.) with the position of the Sub-Pog-Beds and Shale – Pog-Boks complex wedged in between the Cukali Zone beneath and the Albanian Alps above it. Violett lines indicate the transects A (Kir River transect) and B (Shala River transect).

2. DISCUSSIONS

In Horaček *et al*., (2023), it was proposed that parts of the Xhani Shale—representing the uppermost portion of the Cukali Zone, which is the Albanian equivalent of the Budva Zone in Montenegro—should in fact be reassigned to the Bishkaz–Shale Sheet of the Albanian Alps, thus constituting its lowermost unit. However, based on the results of ongoing conodont-based stratigraphic studies and newly recognized tectonic complexities that had previously been overlooked, this interpretation must

now be revised. The original model, as described by Gaetani *et al*., (2015), which presented the Boks and Plan Formations as stratigraphically successive basal Triassic units, has proven to be inaccurate for two key reasons:

i. The base of the Plan Formation is older (Lower Triassic) than the top of the Boks Formation (Middle Triassic); and

ii. The two formations represent markedly different facies, deposited in distinct paleogeographic environments. Specifically, the Boks Formation is interpreted as a deep-water trench-fill deposit, whereas the Plan Formation exhibits a shelf-proximal, clastic to hemipelagic character (see Figures 4–6).

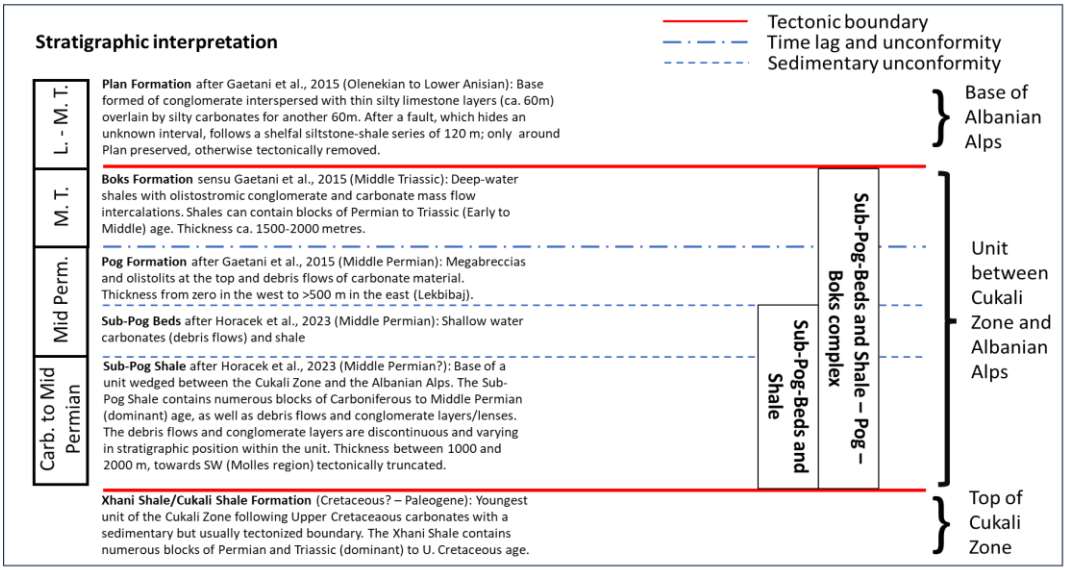

Fig. 4: Schematic description of the sedimentary and tectonic scheme of the Sub-Pog-Beds and Shale – Pog-Boks complex at the base of the Albanian Alps (northern Albania), as exposed in the Kir River valley. At other localities (e.g. Valbona valley) the lowermost unit(s) of the Albanian Alps are (to our knowledge) either not exposed or not present. Carb. = Carboniferous. Mid Perm. = Middle Permian. L. – M. T. = Lower to Middle Triassic. U. = Upper.

Therefore, we conclude that the base of the Plan Formation represents the oldest part of the Albanian Alps, which have been southward-thrust over the underlying, highly folded rocks along a relatively flat thrust plane for a minimum distance of 10 km. This interpretation is supported by the

presence of a tectonic window of the Boks Formation at Theth (Xhomo *et al*., 2002), which is directly overlain by Middle Triassic shallow-water carbonates of the Albanian Alps. The rocks immediately beneath the Plan Formation—and above the Cukali Shale Formation—namely the Boks Formation, Pog Formation, and the "Sub-Pog Beds and Shale" unit (as defined by Horaček *et al*., 2023, 2025), constitute a distinct tectonic zone situated between the Cukali Zone and the Albanian Alps (Figs. 3–6). This interval comprises sediments of latest Lower Permian—or more likely Middle Permian—to Middle Triassic age, based on evidence from the studied region (Gaetani *et al*., 2015; Horaček *et al*., 2023, 2025). It also contains resedimented older rocks ranging from Carboniferous to Lower Permian in age (Figs. 4–6; Horaček *et al*., 2023; 2025).

The Boks Formation, Pog Formation, and Sub-Pog Beds and Shale consist of olistoliths, olistostromes, megabreccias, and deep-water shales of Middle Permian age, containing remobilized blocks of various older ages (Figs. 4 and 5; Horaček *et al*., 2025). These deposits indicate periods of tectonic and orogenic activity that are currently poorly understood and, until now, largely unrecognized. Consequently, the geodynamic and paleogeographic evolution of this former Palaeotethys region—from the Permian, or possibly even Carboniferous, through to the Middle Triassic—requires thorough re-examination and revision in light of these new data and ongoing research. Moreover, the Budva Zone in Montenegro warrants critical re-evaluation to determine whether it also includes, or is capped by, remnants of the "Sub-Pog Beds and Shale – Pog–Boks" complex beneath the Hochkarst Nappe—features that may have been overlooked in previous studies (e.g., Krystyn *et al*., 2019; Horaček *et al*., 2020). Our findings from Albania potentially support the presence of (likely resedimented) Carboniferous blocks or deposits in the Budva Zone, which were reported in earlier literature (Bukowski 1904;1912) but have not been confirmed by recent investigations (Krystyn *et al*., 2019). However, it is important to note that the Budva Zone is traditionally regarded as equivalent to the Cukali Zone, rather than to the Sub-Pog Beds – Pog–Boks complex.

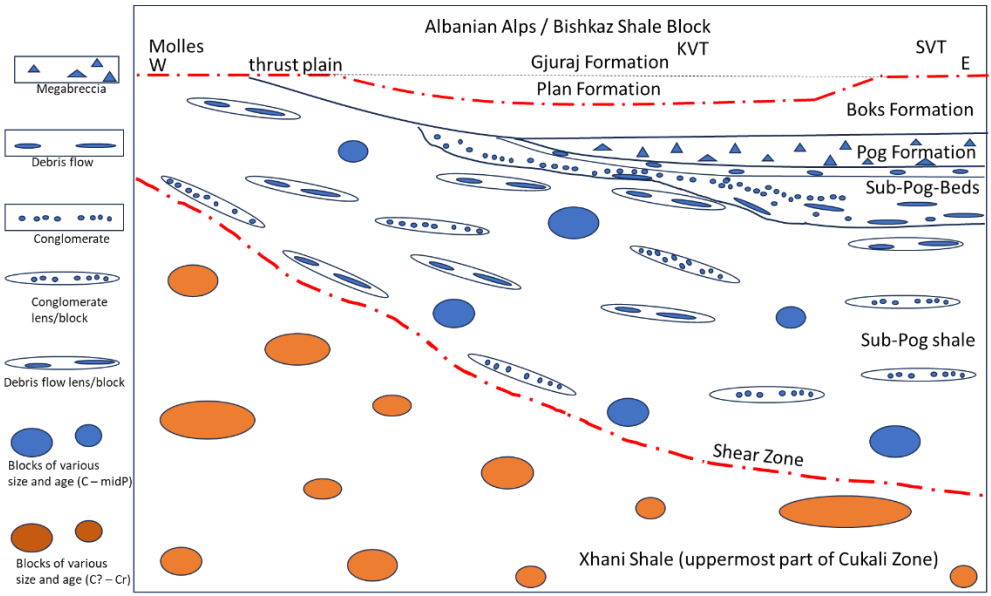

Fig. 5: Schematic sedimentary and tectonic scheme of the Sub-Pog-Beds and Shale – Pog-Boks complex at the base of the Albanian Alps (northern Albania), as exposed between Shala valley (east) and Molles region (to the southwest).

Note that the Upper Permian and Lower Triassic strata are absent within this complex, likely due to tectonic removal. Additionally, the Sub-Pog Beds and Shale – Pog–Boks complex becomes progressively thinner towards the southwest as a result of tectonic truncation. A cataclastic shear zone is also present between the Cukali/Xhani Shale Formation of the Cukali Zone and the overlying base of the Sub-Pog Beds and Shale unit along the Kir Pass Road. Abbreviations used: E = East, W = West, KVT = Approximate position of the Kir Valley Transect, SVT = Approximate position of the Shala Valley Transect, C = Carboniferous, midP = Middle Permian, Cr = Cretaceous.

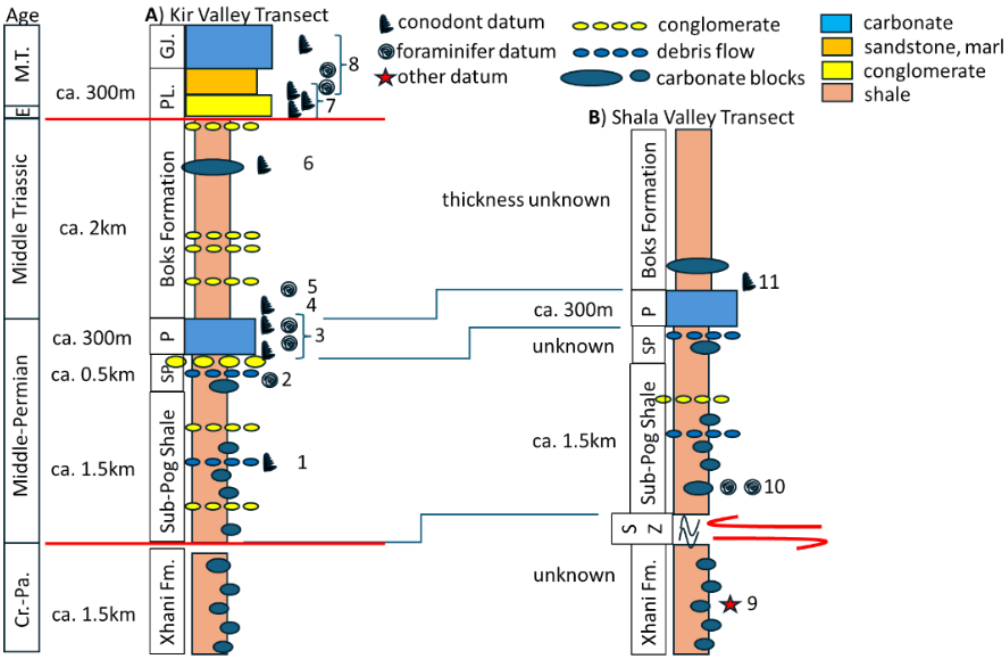

Fig. 6: Sections of the Kir Valley (A) and Shala Valley (B) transects. SP = Sub-Pog Beds, P = Pog Formation, PL. = Plan Formation, GJ. = Gjuraj Formation, Fm. = Formation, Cr.-Pa. = Cretaceous-Paleogene, E = Early Triassic, M.T. = Middle Triassic, SZ = Shear Zone. 1: sample 20/69, Lower Permian, 2: samples 21/112, 21/113L, 24/11, Lower – Middle Permian, 3: sample 18/90 and literature data, Carboniferous and Middle Permian, 4: unpublished, Middle Triassic, 5: Lower Triassic, 6: unpublished, Middle Triassic, 7: unpublished, Lower to Middle Triassic, 8: Lower to Middle Triassic, 9: Couches Rouges block, 10: samples 22/39, 22/40, Lower to Middle Permian, 11: unpublished, Lower Triassic. Data points: 1, 3, 9 are from Horacek et al., 2023; 2, 10 are from Horacek *et al*., 2025; 3, 5, 8 are from Gaetani *et al*., 2015; 4, 6, 7, 11 are unpublished conodont data. Red arrows indicate the shear zone forming the tectonic boundary between Cukali Zone (Xhani Shale Formation) and the base of the Sub-Pog-Beds and Shale – Pog-Boks Complex. Red lines indicate the tectonic boundaries encompassing the Sub-Pog-Beds and Shale – Pog-Boks Complex.

3. CONCLUSIONS

The basal contact of the Albanian Alps—currently mapped at the top of the Cukali/Xhani Shale Formation (Cukali Zone)—should instead be

repositioned to the base of the Early–Middle Triassic Plan Formation. Immediately beneath the Plan Formation, and therefore beneath the Albanian Alps, lies the Sub-Pog Beds and Shale – Pog–Boks complex, spanning Permian to Middle Triassic ages. Although this is a stratigraphically independent unit, its sedimentary characteristics suggest deposition along the same shelf margin as the overlying Alps, with pronounced evidence of erosion and orogenic activity during the Middle Permian and Early–Middle Triassic. The Alps themselves were transported southward over this complex for at least 10 km, as demonstrated by a tectonic window revealing the underlying units. Given its occurrence between the Albanian Alps (above) and the Cukali Zone (below) in northern Albania, it is essential to investigate whether this Sub-Pog Beds and Shale – Pog–Boks complex also extends laterally into Montenegro, appearing between the Budva Zone and the Hochkarst Nappe.

Acknowledgments

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