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# Geotectonic evolution of the Himalaya: Wiping out a century-old hangover

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## ABSTRACT

The author proposes a transformative model for the evolution of the Himalaya, not in the ideal Cenozoic Alpine way of subduction and back-thrusting, arguing that the fundamental structure of the Mountain belt is rooted in the old structural-cum- stratigraphic fabric, not merely the Cenozoic India-Eurasia collision. His work refutes the ”century-old concept” that the Lesser Himalayan structures (the inner Lesser Himalayan Zone, iLHS) are purely products of Cenozoic back-thrusting. The core of the transformative thesis is ”Sans Cenozoic Hangover” (Chakrabarti, 2023). The iLHS zone has a consistent stratigraphy across Pakistan to Arunachal, representing a Paleoproterozoic folded ($F_1$) mosaic (with later imprints) rather than the back-thrust nappe-klippe-thrust scenario over the iLHS portrayed over the past century! The 500 Ma Granitoid belt is identified as a distinct overprint of the late Proterozoic-Cambrian orogeny on the Paleoproterozoic one, with the evolution of the ‘Cambrian’ belt carrying both old and Neoproterozoic-Cambrian signatures. The Main Central Thrust (new MCT) is not a ubiquitous Cenozoic penetration; it is a Cenozoic preference in a long stretch in the higher levels below the exhumed Central Himalayan Crystallines (HHC), coinciding with an older susceptible zone (the PUD zone: Chakrabarti, 2024, 2026). The PUD is a protolith (P), regional unconformity (U) and decollement (D) zone representing a Mesoproterozoic sedimentation gap (<1600–1000 Ma) rather than just a Cenozoic feature; definitely post-Paleoproterozoic impact in varying degrees bewildered workers to consider this old zone of tectonic susceptibility as a MCT zone everywhere. The NNE/NE–SSW/SW trending mineral lineation, long thought to be associated with the Cenozoic thrusting (designated ***a*** lineation), is actually a mimetically superposition on an earlier lineation parallel to the Paleoproterozoic $F_1$ fold axis ($L_1$: ***b*** lineation). Long years of habitat in Alpine (Cenozoic) mode failed to recognise this old ***b*** lineation also as an intersection lineation ($F_1$ fold and its axial planar schistosity) ultimately help define and construct the Paleoproterozoic $F_1$ mega-folds in sections across the $F_1$ axis (NNE-SSW)**.** The common NE-SW geological sections drawn over a century displayed the Cenozoic (and in belts the late Palaeozoic–Cambrian) deformation ($F_2$). The so-called bi-generation garnet and Cenozoic hangover of Naha and Ray (1971a,b, 1972) are discussed: the upper greenschist to lower amphibolite facies ILHS exhibits such an apparent bi-generation (in garnet) feature (volume diffusion in higher metamorphic levels: $M_1$) and the evidence of overthrusting across the “Jutogh Thrust” is considered redundant.

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## 1. Introduction

The century-old concept of Cenozoic evolution of the Himalayan belt, ideally through subduction and back-thrusting, is rejected by the author. Geotectonic evolution of the Paleoproterozoic basement sequence of the Himalaya (iLHS) remained almost unexplored, and the Central Himalayan Crystallines (HHC; Fig. 1, 4) were considered the domain of major Cenozoic tectonism related to subduction and back-thrusting. Central to this paradigm has been the longstanding view that the fold nappe/thrust structure in the Lesser Himalayan Crystallites (LHC; Fig. 1), so characteristic of the inner Lesser Himalayan Sequence (iLHS: older sequence of the LHS separated with a gap by the southern Neoproterozoic oLHS and the HHC with a basal new MCT zone to the north: Fig. 4), is a direct consequence of the Cenozoic Himalayan orogenesis, like the evolution of the Alps. The author has reviewed the Alpine model of evolution of the Himalaya, based on decades of involvement with the terrain and a basic education in the frontal peninsular Precambrians under great teachers at Presidency College (Kolkata) during the sixties.

According to the author, the so-called nappe/thrust structure in the inner Lesser Himalayan Sequence (iLHS) is not a product of Cenozoic tectonic processes, this is instead a mega-scale Paleoproterozoic $F_1$ fold rooted to the folded ($F_1$) Paleoproterozoic inner window zone sequence (Fig. 2). Such deep rooted mega-fold represents the oldest tectonic signature in the Himalayan terrain which was later affected by late Neoproterozoic-Cambrian and Cenozoic impress. A key focus of this work is the reinterpretation of the Main Central Thrust (new MCT; Chakrabarti, 2023, 2024, 2026) and its regional continuity. The MCT in the axial zone (between the iLHS and the HHC) very commonly coincides in the region east of the Pakistan sector with a composite PUD zone—a protolith boundary (P), regional unconformity (U), and décollement (D)— that marks a long-lived tectono-stratigraphic discontinuity spanning from Paleoproterozoic end to Neoproterozoic (a Mesoproterozoic geological gap).

However, the Cenozoic new MCT zone (Chakrabarti, 2023, 2024, 2026) above the old MCT (Heim and Gansser, 1939) cannot be marked in the Pakistan sector across the iLHS nor between the iLHS and the outer Lesser Himalayan Sequence (oLHS) to the east. This regional framework casts doubt on the assumed regional extent of Cenozoic thrusting. It highlights the inherited complexities of the Himalayan architecture: the so-called omnipresent Cenozoic MCT has limited access to the LHS sequence to the south. Unfortunately, post-Paleoproterozoic impact, in varying degrees, bewildered workers into considering the old PUD zone of tectonic susceptibility as a MCT zone everywhere, even in the LHS (could not designate one such between the Semi and the Kaimur groups in the frontal peninsula (Chakrabarti, 2023)).

The author highlights the work of Carosi and his team (Carosi et al., 2018) on the exhumation phenomenon in the Central Himalaya and on the secondary role of the MCT in Cenozoic regional back-thrusting (Chakrabarti, 2024)! Comparative analysis with the Pakistan sector, including the Khairabad Thrust and the Tanawal- Gadaf formations, reinforces the conclusion (Chakrabarti, 2024, 2026) that much of the Himalayan basement, particularly west of Nanga Parbat, is Paleoproterozoic in age (iLHS) and lacks direct evidence of Cenozoic conceived nappe tectonics or tectonothermal activation as evidenced from the central Himalayan domain.

Stratigraphic parallels across the inner Lesser Himalaya (iLHS) from Pakistan to Arunachal further support a regionally coherent, yet deeply ancient, structural and metamorphic history of the iLHS terrain, akin to that of the frontal peninsula. The author also addresses key metamorphic ($M_1$) markers—such as zoned garnet growth (Chakrabarti, 1983, 2024: Fig. 3), high-grade $F_1$-$M_1$ fold and mineral lineation (Fig. 3d) and the absence of Cenozoic granitoids in the iLHS, pointing to a prominent regional Paleoproterozoic metamorphic event ($M_1$). The evolution of the Cambrian granitoids is tied to the locale ($F_1$ fold core) of the earlier high-grade ($M_1$) regional metamorphism, further distancing the core (iLHS) from the Himalayan metamorphic imprint and major Cenozoic evolution.

With his decades of study of the Himalaya, the author invites the workers of the terrain to review traditional models and consider the entombed picture in its entirety!

 

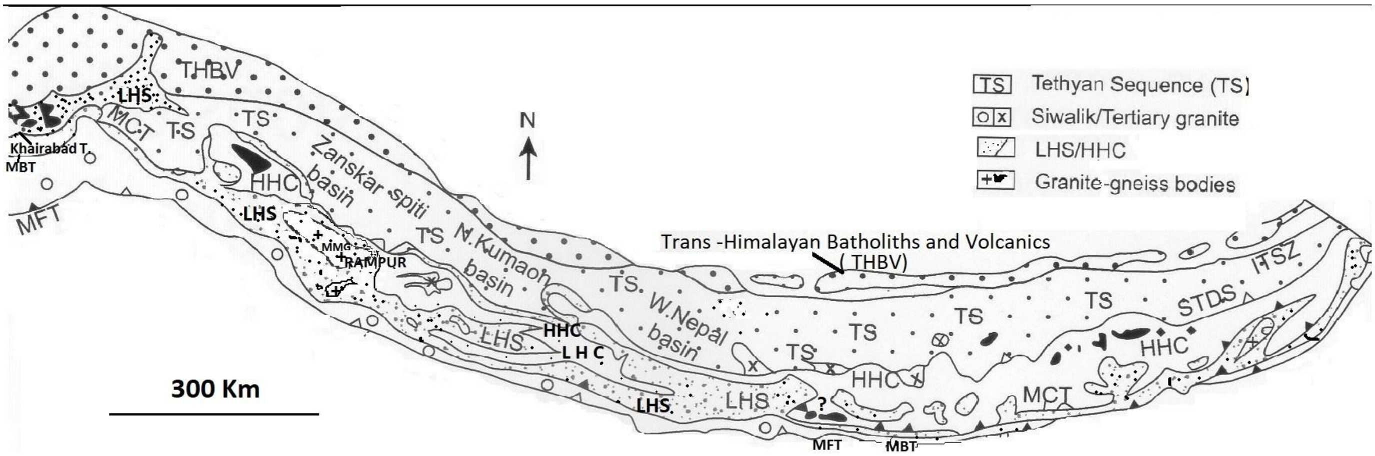


Fig. 1. Himalayan belt exhibiting the different geological zones (after Chakrabarti, 1996, 2016).

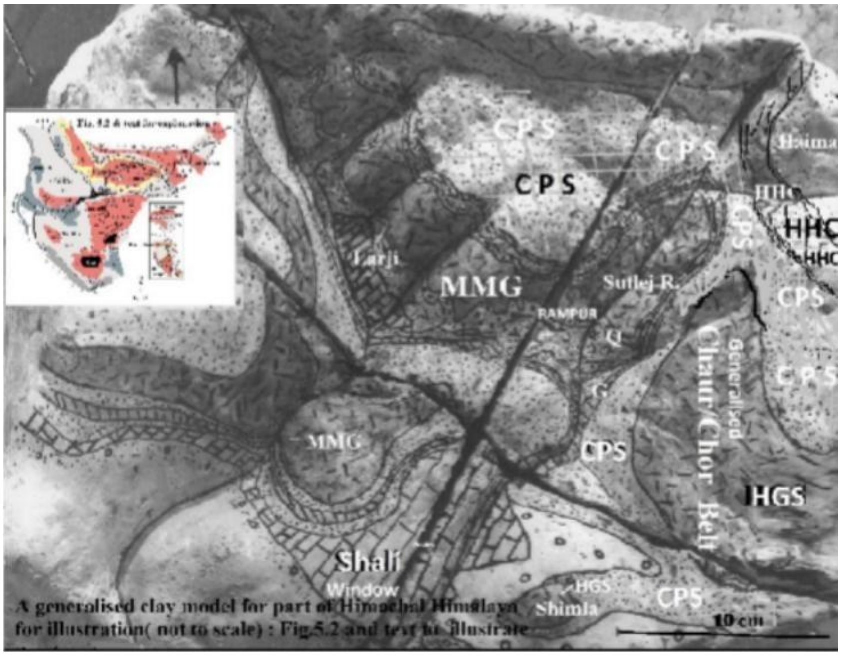


Fig. 2. A 3D presentation of the Shimla-Rampur (Himachal Himalaya) terrain. ***Inset:*** Geological map of Shimla-Rampur area: HGS (Jutoghs), CPS (Salkhalas/Chails), G (Mylonite Gneiss), MMG (Migmatite Gneiss-granite correlated with HGS, both framed by CPS).

## 2. Tectonic Evolution of the Himalaya – A New Picture

O.N. Bhargava, a legendary worker in the Himalaya, remarked that "the British geologists, steeped in Alpine geology, initiated the geological survey in India. Naturally, they transported the Alpine concept to the Himalaya. As detailed mapping progressed in the Himalaya, gaps in the Alpine model began to appear, such as the pre-Cenozoic tectonic palimpsest" (*in* Chakrabarti, 2026, Introduction p. xxi). The author's previous book publication (Chakrabarti, 2023) and the following article (Chakrabarti, 2024) focused on Precambrian geotectonics in the Himalayan terrain, where he demonstrated that the so-called Cenozoic nappe structure is actually a Paleoproterozoic mega-fold rooted in the inner window zone, occupied by the folded ($F_1$) Paleoproterozoic rocks. Chakrabarti (2026) provides an in-depth review and synthesis of the Precambrian and Phanerozoic geology of the Himalayan terrain, an insightful perspective on the evolutionary picture, and a distinctive tectonic process involving subduction-induced Cenozoic geological changes that challenge the century-old Alpine back-thrusting model. The author agrees with Dr Bhargava above - "Just as 'All

 

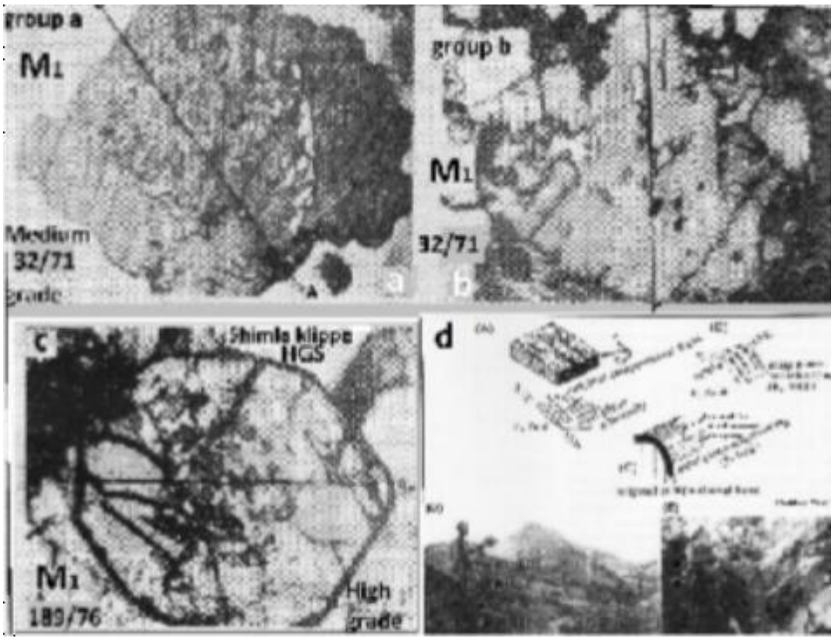


Fig. 3. a. $M_1$ zoned garnet (A-B probe line), b. $M_1$ separate grain in matrix, c. $M_1$ garnet is in a higher grade. Simla Himalaya (probe data in Chakrabarti, 1983, 2016, 2023, 2026). (dA). $F_1$ fold & b lineation, (dB). $F_2$ refolding, (dC). $F_1$ fold form (black) with trace of $L_1(M_1)$ & superposed mimetic crystallization ($M_2$), (dD). $F_1$ fold in Rampur Quartzite, (dE). $F_2$ fold in Rampur Quartzite.

that glitters is not gold', not all mountains are Alps - each one has its individuality".

Identification of the new MCT (henceforth MCT) with a deeper PUD (P: protolith-U: unconformity-D: decollement) zone is particularly significant. The MCT coincides with the PUD zone in a large part of the axial Himalayan domain – the PUD zone represents a Mesoproterozoic sedimentation gap over which the Neoproterozoic HHC (or the equivalents, like the Simla Slate or the Tanawals in the Lesser Himalaya) was deposited. The widespread occurrence of the PUD zone cannot always be coincided with the MCT zone positioned in the Higher Himalaya ( PUD zone also occurs between the iLHS and oLHS and long hangover had also put a MCT zone there: Fig. 4). The author (Chakrabarti, 2023) discussed on how much of the Himalayan terrain experienced the back-thrusting phenomenon (and movement along the MCT) and on extent of the MCT zone along the PUD zone (*no PUD zone without a thermally activated HHC domain above is a MCT zone*: Chakrabarti, 2023, 2024, 2026)!

The Pakistan sector is not included within the Cenozoic Himalayan belt. The Khairabad Thrust zone between the Neoproterozoic Tanawal and the Paleoproterozoic Gadaf formations (a PUD zone: Fig. 1) is coeval with the MCT zone in central Himalaya; however, the Neoproterozoic Higher Himalayan Crystallines (HHC) east of Nanga Parbat with pronounced Cenozoic tectonothermal evolution is different from the synchronous Tanawals without any such Himalayan signatures. The Nanga Parbat (NP) syntaxis and nearby ones, according to the author, are a product of a transpressional zone at the western edge of the subducting Indian plate during 55-45 Ma. Further, a vast portion of the Pakistan terrain, including the NP domain, is within the Paleoproterozoic (iLHS), which cannot host the new MCT (Chakrabarti, 2024, 2026).

The iLHS terrain stretching from Pakistan to Arunachal has a fairly uniform stratigraphy and tells many old stories not to be attributed to a Cenozoic hangover! And a review of the iLHS of the Himalayan terrain from Pakistan to Arunachal Pradesh provides a guiding stratigraphic framework for addressing regional issues such as the position of Lingtse-Jaisidanda, the spread of the MCTZ (Paleoproterozoic) overlain by a new MCT, and the age of the Paro Fm., etc. The pre-2173 Ma oldest exposed Kishar (also reported as old as 2931±5 Ma), the Karora-Gadaf formations with 1850 Ma intrusive (?) granite-gneiss, and the Neoproterozoic Tanawals over a pronounced unconformity (PUD zone: Mesoproterozoic) match the Proterozoic picture across the entire

 


Fig. 4. The LHC (iLHS) bodies in western Uttarakhand (Garhwal) Himalaya. PUD and other zones shown.

Himalayan terrain. The PUD zone between the iLHS and the oLHS has no tectonic relation to the pronounced manifestation along the MCT zone (coinciding with the PUD Zone between the iLHS and the HHC in the axial zone of the central and eastern Himalaya). Bhargava (2000) assigned the carbonates (Shali-Larji-Deoban) overlying the Salkhalas (CPS in Fig. 2) an end-Paleoproterozoic age (1500–1600 Ma), with a gap (PUD zone of the author) followed by the Simla Group at 1000 Ma (& Tanawals, HHC).

The NNE/NE-SSW/SW trending mineral lineation ($F_1$-$L_1$, Fig. 3), commonly tied to the conceived direction of Cenozoic thrusting, actually mimetically superposes an earlier lineation ($F_1$) defined commonly by higher grade mineral (Paleoproterozoic: $M_1$). Zoned garnet in the upper greenschist-lower amphibolite facies iLHS rocks (Jutoghs in the Simla terrain with a reported underthrust 'Chails' (Naha and Ray, 1971a,b, 1972) so commonly considered bi-generation (Naha and Ray, 1971a,b, 1972) actually represents a single generation ($M_1$) with varying growth rate (Chakrabarti, 1983; Fig. 3)).

The presence of a 500 Ma granitoid belt in the iLHS was reviewed earlier (Chakrabarti, 1993, 2016, 2023, 2024, 2026). The cordierite-bearing precursor and a later (Cambrian) two-mica phase make the genesis of the bodies in locales of high P-T (Paleoproterozoic: $M_1$) in LHC a guiding exercise, along with the absence of Cenozoic granite bodies. The Cenozoic history of evolution of the HHC was reviewed earlier (Chakrabarti, 2024, 2026) to understand the role of this domain (plus the MCT) in the Cenozoic back-thrusting phenomenon. The subduction history together with exhumation of the UHP rocks, an initial exhumation of UHP assemblage in Neelam-Tso Morari domain and an approximately coherent shift from steep to low-angle subduction after middle Eocene with breakoff of the Neo-Tethyan slab and a regime of transition from continental subduction to collision tectonics were also considered (Chakrabarti, 2024, 2026).

The author traced the so-called Cenozoic nappe structures in the LHC to the Paleoproterozoic inner window zone as the oldest ($F_1$) mega-fold (Chakrabarti, 1978, 2023, 2024, 2026) and isotope data specially during the last two decades (Chakrabarti, 2023, p. 115–118; Imayama and Arita, 2008) also support the author that the Neoproterozoic HHC domain cannot contribute to Paleoproterozoic nappe/klippe bodies in the iLHC domain (Fig. 4): *the century-old concept of Cenozoic subduction-related back-thrusting and nappe development (as in the Alps) scenario, therefore, is not tenable!*

Work on exhumation in the axial zone of central Himalaya specially during Oligocene period has been exhaustive (e.g. Carosi et al., 2018; Chakrabarti, 2023, 2024, 2026 for details) and the author reviewed all reasonable observations on Cenozoic activation in Chakrabarti (2024, 2026) to conclude that the Eocene-early Miocene period had a major role in the rise of the Himalaya and a limited role of the MCT zone in the back-thrusting picture induced by varied state of the subduction kinetics; the prominent

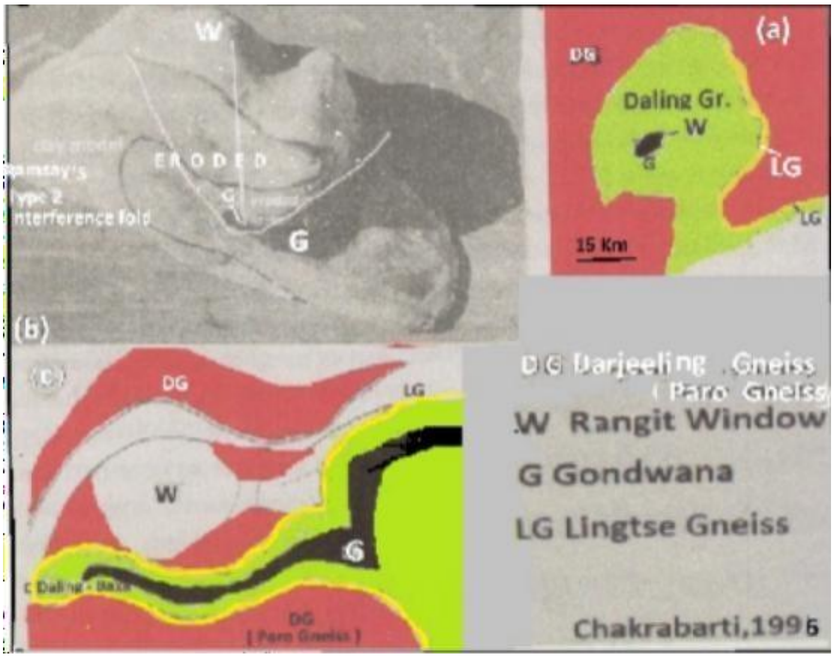


Fig. 5. (a). Geology of Darjeeling-Sikkim Himalaya with Rangit window (W), (b). Clay model of the folded terrain ($F_1$-$F_2$) with Gondwana(G) exposed as a window (W) due to erosion in a, b & c.

Fig. 6. A tentative NE-SW river section across a Paleoproterozoic sequence showing the Cenozoic (+/ Cambrian) folding; the facing fold is marked to indicate the presence of $F_1$ across.

phase of subduction, however, was accompanied by exhumation of UHP assemblages in the stretch between the Neelam Valley (Pakistan) and the Zanskar domain (Rehman et al., 2008; Rehman, 2019; Chakrabarti, 2026) between 55 and 45 Ma.

## 3. Discussion

The author rejects the Alpine model of subduction and back-thrusting resulting in events such as nappe and thrust emplacement over the iLHS; the initial phase of subduction and exhumation, however, is well established. Also, exhumation in the Higher Himalayan domain during 41-13 Ma (Carosi et al., 2018) in the HHC of the central Himalaya is well illustrated (Chakrabarti, 2026). Establishment of the PUD zone and superposition of the new MCT along the PUD in the axial zone (the new MCT below the HHC) of the central-eastern Himalaya, and absence in the Pakistan sector, are reviewed. The so-called MCT zone between the iLHS and the oLHS is a conspicuous geological (Mesoproterozoic) gap—

 

the PUD zone with tectonic susceptibility; the high wavelength folds ($F_2$) and their accompanying reverse faults in the LHS and further south justifiably represent the Cenozoic effect of the subduction process.

The domains of the iLHS (Fig. 5) with $F_1$ and later $F_2$ superposition have been viewed as apparently responding differently to deeper quakes, as in the Nepal 2015 earthquake, where the path of the near-surface impulses was possibly guided by such infolded sectors (Chakrabarti, 2026). The author was surprised for a long time that generations of workers were absorbed in the Cenozoic impression, ignoring the old Paleoproterozoic signatures; the NE-SW river/nalla sections were studied in detail, not across, with a century-old hangover! As repeatedly stressed by Chakrabarti (1978, 1996), the ~NE-SW geological sections (parallel to $F_1$ fold axis; so common river sections were alluring) in a Paleoproterozoic terrain would display the folded sequence not folded by $F_1$, but only by $F_2$ (Fig. 6) and an unit deformed by $F_1$ folding would occur at different tectonic levels apparently as different units or thrust sheets (provoking hangover of "Thrust").

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## CRediT statement

BKC - Conceptualisation, Formal analysis, Investigation, Data curation, Original draft preparation, Finalisation of the manuscript and Visualisation

## Declaration of competing interest

The author declares no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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