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Mid-Cretaceous rapid denudation of eastern Tibetan Plateau: Insights from detrital records at the southwestern corner of Sichuan Basin: A comparative review

Bello Aliyu^{1,*}, Safiratu Hashimu², Hafsat Muhammad³

¹ State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Chengdu University of Technology, Chengdu, China

² Department of Microbiology, Federal University of Gusau, Zamfara State, Nigeria

³ Department of Geological Science, Faculty of Science, Federal University Gusau, Zamfara State, Nigeria

*E-mail address: belloncyaleeyu@gmail.com

ABSTRACT

This review examines the study titled "Mid-Cretaceous Rapid Denudation of Eastern Tibetan Plateau: Insights from Detrital Records at the Southwestern Corner of Sichuan Basin", which investigates the geological evolution of the Tibetan Plateau during the mid-Cretaceous period. Utilizing a multi-proxy approach, including detrital zircon geochronology and heavy mineral analysis, the study provides insights into sediment provenance, tectonic mechanisms, and the implications of rapid denudation processes. By comparing sedimentary records from the Sichuan Basin with those from adjacent regions such as the Yidun and Lhasa terranes, the research highlights the interplay between tectonic uplift and erosion, offering a comprehensive understanding of how these processes have shaped the landscape. This review emphasizes the significance of integrating geological data with climatic and ecological contexts to better understand the Tibetan Plateau's evolution and its impact on regional climate dynamics. Ultimately, it calls for further interdisciplinary research to explore the complex interactions between geology, climate, and human activities in this critical region.

Keywords: Tibetan Plateau, Denudation, Detrital, Zircon Geochronology, Sediment Provenance, Tectonic Evolution

1. INTRODUCTION

The Tibetan Plateau, often referred to as the "Roof of the World," is a region of immense geological significance and complexity [1]. Its formation and evolution have been a focal point of research for geologists and tectonicists, particularly due to its role in shaping global climate patterns and influencing monsoon systems across Asia [2]. Among the various periods of interest, the Mid-Cretaceous stands out as a critical phase characterized by rapid denudation and tectonic uplift [16]. The paper "Mid-Cretaceous Rapid Denudation of Eastern Tibetan Plateau: Insights from Detrital Records at the Southwestern Corner of Sichuan Basin" addresses this pivotal period, providing new insights into the sedimentary processes and tectonic mechanisms that shaped the eastern Tibetan Plateau.

Despite extensive research on the tectonic history of the Tibetan Plateau, much of the focus has traditionally been placed on the Late Mesozoic (Late Triassic to early Jurassic) and Cenozoic eras as argued by [4-7]. This has resulted in a relative lack of understanding regarding the Late Mesozoic, particularly the Middle to Late Jurassic and Cretaceous periods. The authors of this study highlight this gap, emphasizing that a comprehensive understanding of the plateau's early uplift and growth mechanisms requires a closer examination of these less-studied intervals. Recent advancements in low-temperature thermochronology have revealed significant regional uplift and denudation events during the Late Jurassic to Early Cretaceous [6], [8], and [9], suggesting that substantial geological changes were occurring even before the well-documented India-Asia collision [10], [11].

The Sichuan Basin, located adjacent to the eastern Tibetan Plateau, serves as an ideal setting for investigating these processes due to its rich sedimentary record [11], [13]. The basin contains extensive deposits that can provide valuable information about paleo-tectonic events during orogenic development [12], [14]. By analyzing detrital zircon ages and heavy mineral assemblages from Cretaceous strata in this region, researchers can trace sediment provenance and reconstruct the geological history linked to tectonic uplift.

This review aims to extend the findings of the original paper by incorporating comparative studies with other regions within the Tibetan Plateau and adjacent areas. By examining sedimentary records from locations such as the Yidun Terrane and Lhasa terrane, we can gain a broader perspective on regional tectonics and sedimentary processes. Understanding these relationships is crucial for unraveling the complex interplay between tectonics, erosion, and sedimentation during a time when significant geological transformations were taking place.

This review will not only synthesize the insights presented in the original study but also contextualize them within a wider geological framework. By doing so, it aims to contribute to our understanding of the mid-Cretaceous denudation processes that played a vital role in shaping the eastern Tibetan Plateau's landscape and geological history.

2. METHODOLOGY

The methodology employed in the study "Mid-Cretaceous Rapid Denudation of Eastern Tibetan Plateau: Insights from Detrital Records at the Southwestern Corner of Sichuan Basin" is multifaceted, integrating various analytical techniques to investigate sediment provenance and tectonic evolution during the Cretaceous period. This review not only summarizes the

original methods but also emphasizes how these techniques can be applied to comparative studies with other regions, enhancing our understanding of the broader geological context.

2. 1. Fieldwork and Sample Collection

The research commenced with extensive fieldwork in the southwestern corner of the Sichuan Basin, an area known for its rich sedimentary deposits [17]. The authors focused on a continuous stratigraphic section approximately 1.2 kilometers thick, which includes various Cretaceous strata. This specific location was chosen due to its geological significance and prior research that established a baseline understanding of the region's sedimentary history.

During fieldwork, sediment samples were systematically collected from multiple stratigraphic horizons. This careful sampling strategy ensured that the dataset accurately represented variations in sediment characteristics over time. The authors meticulously documented each sample's location and depth, which is crucial for correlating sedimentary features with geological events and for making comparisons with other regions.

2. 2. Detrital Zircon Geochronology

A central technique used in this study is U-Pb dating of detrital zircon grains. Zircon is a robust mineral that can withstand weathering and transport, making it an ideal candidate for provenance studies [18-20]. After extracting zircon grains from the collected sediment samples, the authors subjected them to U-Pb geochronology analysis. This method involves measuring the ratio of uranium to lead isotopes within zircon crystals, allowing researchers to determine when these grains formed, this is also done in the previous of [21-24].

By analyzing the age distribution of detrital zircon, the authors could infer when sediments were deposited and identify potential source regions. This information is invaluable for understanding the timing of geological events and their impact on sedimentation processes. In comparative studies, similar zircon dating techniques can be applied to sediment samples from adjacent regions such as the Yidun Terrane or Lhasa terrane, facilitating direct comparisons of sediment provenance and tectonic histories.

2. 3. Heavy Mineral Analysis

In addition to zircon dating, heavy mineral analysis was conducted to further characterize the sedimentary materials. Heavy minerals such as garnet, tourmaline, and zircon provide insights into sediment composition and provenance. The authors performed a systematic examination of heavy mineral assemblages from different stratigraphic levels. This has been a proven and reliable process as done in [25-29].

This analysis not only helps identify source rocks but also sheds light on the environmental conditions under which these sediments were deposited. By comparing heavy mineral compositions across different samples, both within the Sichuan Basin and in other regions, researchers can trace changes in sediment sources over time and link these shifts to tectonic events across a broader geographical context.

2. 4. Paleocurrent Analysis

To complement their findings regarding sediment provenance, paleocurrent analyses were conducted using sedimentary structures observed in the field. By measuring the orientation of cross-bedding and other sedimentary features, researchers reconstructed ancient

flow directions. Understanding these flow patterns is crucial for interpreting how sediments were transported within the basin and how tectonic uplift influenced sediment distribution. In comparative studies, paleocurrent data from other basins can be integrated to assess how regional tectonics influenced sediment transport dynamics across different geological settings

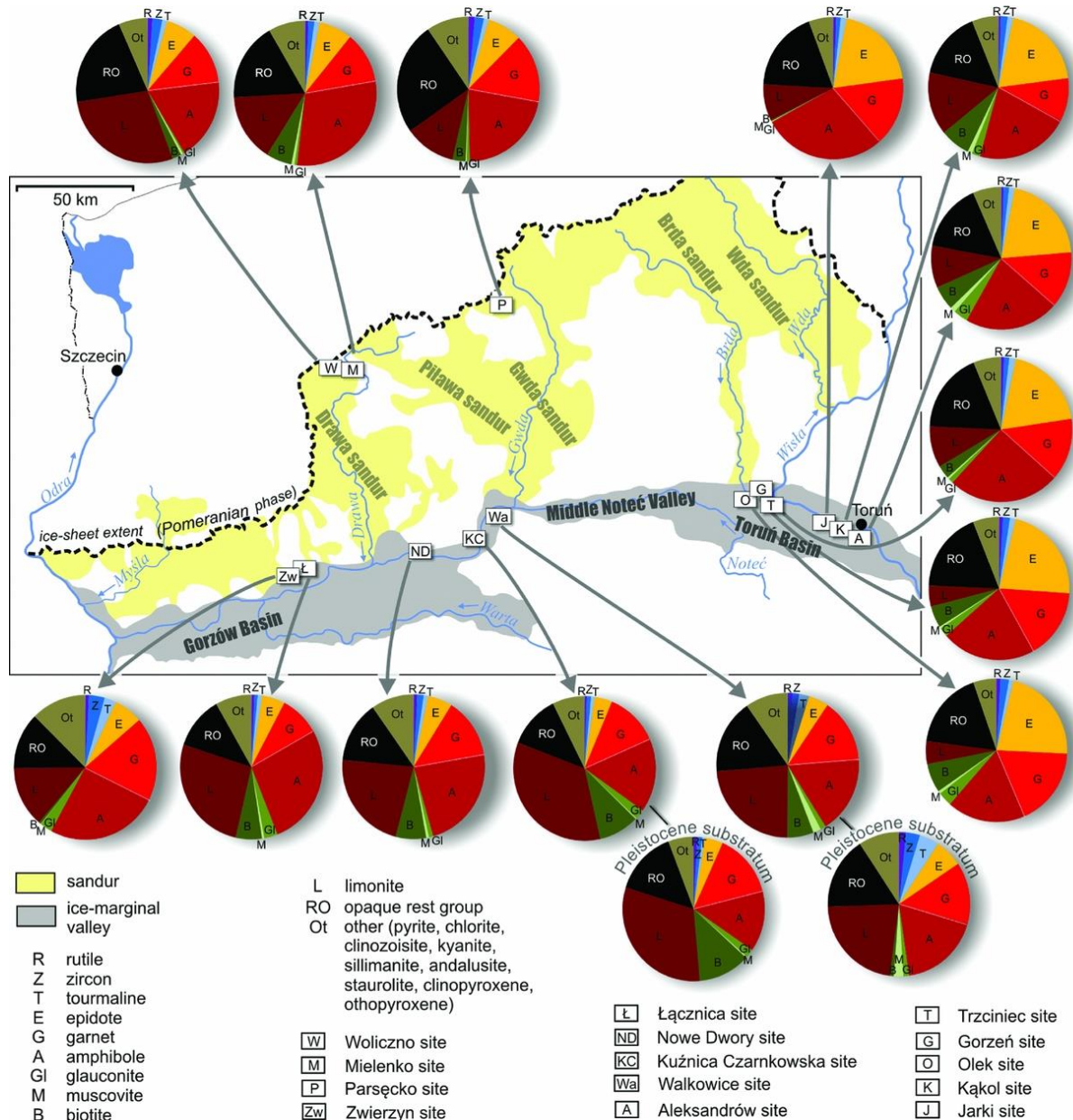


Figure 1. Heavy Mineral Analysis: Cambridge.

2. 5. Data Integration and Interpretation

The final step in their methodology involved integrating all collected data, geochronological, mineralogical, and paleocurrent information, to construct a comprehensive

picture of tectonic evolution during the Cretaceous period. By correlating changes in sediment provenance with known tectonic events such as regional uplift and denudation phases, the authors were able to draw meaningful conclusions about the dynamic processes shaping the eastern Tibetan Plateau.

This integrative approach is particularly valuable for comparative studies, as it allows researchers to align findings from different regions chronologically and geologically. Such comparisons can reveal broader patterns in tectonic activity and sedimentation processes across mountainous terrains worldwide.

The multi-proxy methodology combines rigorous fieldwork with advanced analytical techniques to provide robust insights into the mid-Cretaceous geological history of the eastern Tibetan Plateau. By employing a holistic approach that integrates various data types, this study effectively addresses key questions regarding sediment provenance and tectonic evolution. The methodologies outlined not only enhance our understanding of local geological processes but also offer valuable frameworks for conducting comparative studies that deepen our knowledge of tectonic activity in diverse geological settings globally.

3. REGIONAL CONTEXT

The sedimentary records from the Sichuan Basin provide a critical lens through which to examine the tectonic evolution of the eastern Tibetan Plateau during the mid-Cretaceous period. This region, characterized by its complex geological history, serves as a significant point of comparison with adjacent areas such as the Yidun Terrane and Lhasa Terrane. Each of these regions offers unique insights into sediment provenance and tectonic mechanisms, enhancing our understanding of the broader geological processes at play.

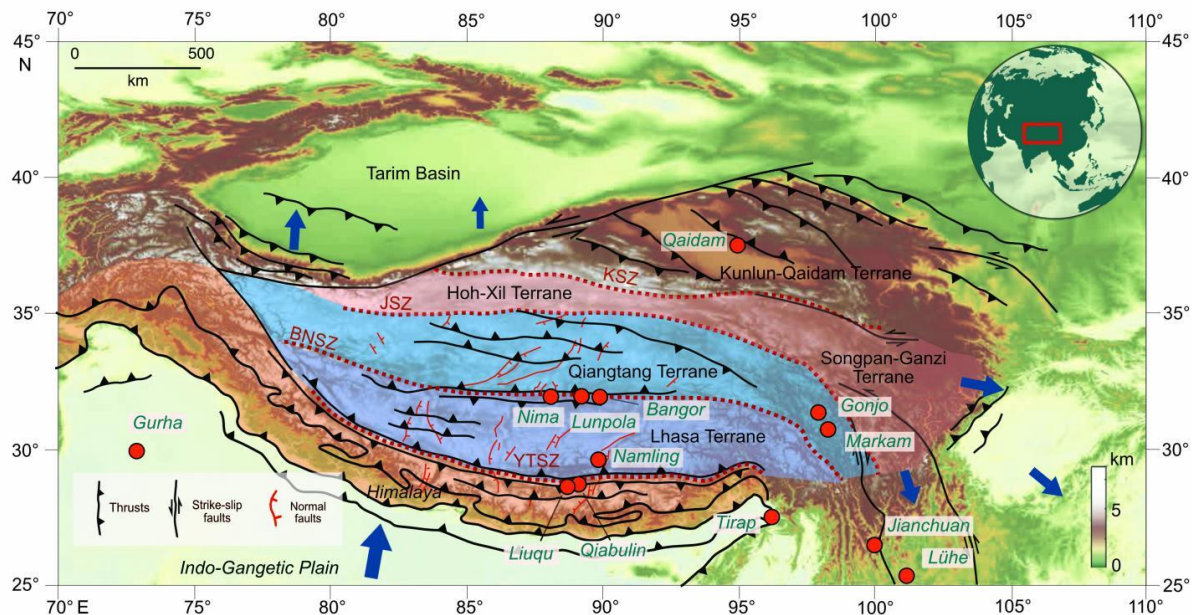


Figure 2. The 'Uplift of the Tibetan Plateau' Myth | Science Blogs

In the Sichuan Basin, recent studies reveal two distinct changes in sediment provenance during the Cretaceous, primarily sourced from the Songpan-Ganzi fold belt and the Longmenshan orogenic belt. The detrital zircon analysis indicates that sediments were derived from these uplifted areas, reflecting a dynamic interplay between tectonic activity and sedimentation. In contrast, the Yidun Terrane, located to the southwest of the Sichuan Basin, presents a different sedimentary narrative. Provenance analyses from this region suggest that sediments were sourced from both local and distant geological formations, including rocks from the Yidun and Songpan-Ganzi terranes. The presence of Late Mesozoic alluvial strata in nonmarine basins within the Yidun Terrane indicates that these areas were also influenced by regional tectonics associated with the collision between the Lhasa and Qiangtang terranes.

The Lhasa Terrane further complicates this picture. It has been shown to supply sediments primarily from Cenozoic volcanic activity and older terranes, indicating a different sedimentary regime influenced by its unique tectonic history. The Lhasa Terrane is characterized by significant crustal thickness and has undergone various tectonic events leading to its current geological configuration. The differences in sediment provenance among these regions highlight how local geological histories shape sedimentary processes. For instance, while the Sichuan Basin reflects a dynamic interplay of uplift and erosion linked to nearby orogenic events, the Yidun and Lhasa terranes exhibit distinct geological histories that influence their sediment composition.

Moreover, these regional contexts reveal important insights into how tectonic uplift mechanisms differ across the Tibetan Plateau. In areas like the Sichuan Basin, rapid denudation is closely tied to active tectonic uplift associated with nearby mountain-building processes. Conversely, in the Yidun Terrane, sedimentation appears to be influenced more by inherited geological structures and earlier tectonic events that shaped its landscape.

Comparison of the findings from the Sichuan Basin with those from adjacent regions like the Yidun and Lhasa terranes underscores the complexity of sedimentary processes in eastern Tibet. These insights not only enhance our understanding of local geological dynamics but also contribute to broader discussions about tectonic activity and landscape evolution across mountainous terrains globally. By integrating data from these various regions, researchers can better contextualize regional uplift mechanisms within a comprehensive framework of Tibetan Plateau evolution.

4. TECTONIC MECHANISMS

The tectonic mechanisms driving the uplift of the Tibetan Plateau are complex and multifaceted, reflecting a range of geological processes that have occurred over millions of years. Understanding these mechanisms is crucial for interpreting the rapid denudation observed in regions like the Sichuan Basin and for contextualizing the broader geological evolution of the plateau.

4. 1. Crustal Shortening

One of the primary mechanisms attributed to the uplift of the Tibetan Plateau is crustal shortening, which occurs as a result of the collision between the Indian and Eurasian tectonic plates [31]. This process involves compressional forces that lead to thickening of the crust, resulting in significant vertical uplift. Studies suggest that this mechanism has played a vital

role in shaping various orogenic belts within the plateau, particularly in areas where intense tectonic activity has caused large-scale deformation.

As crustal shortening continues, it contributes to the development of mountain ranges and influences sedimentary processes in adjacent basins. In the Sichuan Basin, for example, evidence of rapid denudation correlates with periods of active tectonic uplift, highlighting how crustal shortening not only affects topography but also impacts sediment transport and deposition patterns.

4. 2. Edge-Driven Convection

In addition to crustal shortening, edge-driven convection has emerged as another important mechanism influencing uplift in certain areas of the Tibetan Plateau. This process involves thermal anomalies within the mantle that drive convective currents, leading to localized uplift along plate boundaries. Research indicates that edge-driven convection can result in significant vertical movements in regions where lithospheric thickness varies, creating a dynamic interplay between mantle processes and surface geology.

In NE Tibet, for instance, studies have suggested that edge-driven convection may explain some of the prominent geological phenomena observed in this region, such as vertical crustal uplifting and associated volcanism. This mechanism provides a complementary perspective to crustal shortening by emphasizing how mantle dynamics can also drive surface uplift.

4. 3. Mantle Delamination

Another critical process contributing to the uplift of the Tibetan Plateau is mantle delamination. This phenomenon occurs when dense lithospheric material detaches from the overlying crust and sinks into the mantle.

As this material is removed, it can lead to buoyancy-driven uplift of the overlying crust. Recent research has proposed that mantle delamination is a key driver behind the plateau's growth, particularly in areas where subduction-related processes have altered lithospheric dynamics [47-49].

The gradual peeling away of lithospheric mantle from the overriding plate results in melting and subsequent uplift, which aligns with observations of progressive surface elevation across the plateau [50], [51]. This model not only accounts for geological features such as magmatism but also explains variations in uplift rates across different regions.

4. 4. Integrating Mechanisms

The interplay between these tectonic mechanisms, crustal shortening, edge-driven convection, and mantle delamination—highlights the complexity of processes shaping the Tibetan Plateau. Each mechanism contributes uniquely to uplift and denudation patterns observed in various regions, including the Sichuan Basin. By examining these processes collectively, researchers can better understand how they interact to influence regional geology.

For instance, while crustal shortening may dominate in certain areas during periods of intense tectonic activity, edge-driven convection could play a more significant role in others where thermal dynamics are at play. Similarly, mantle delamination may explain localized uplift events that coincide with broader tectonic shifts.

A good understanding of the tectonic mechanisms driving uplift in the Tibetan Plateau requires a comprehensive approach that considers multiple processes operating simultaneously.

By integrating insights from various studies on crustal shortening, edge-driven convection, and mantle delamination, researchers can develop a more nuanced understanding of how these mechanisms contribute to rapid denudation observed in regions like the Sichuan Basin. This holistic perspective is essential for unraveling the complex geological history of one of Earth's most significant mountain ranges and its ongoing evolution.

5. CHRONOLOGICAL FRAMEWORK

Establishing a robust chronological framework is essential for understanding the uplift and denudation history of the Tibetan Plateau, particularly during the mid-Cretaceous period. This framework allows researchers to correlate geological events across different regions and gain insights into the timing and mechanisms of tectonic processes that have shaped this complex landscape.

5. 1. Integrating Chronological Data

To construct a comprehensive timeline of uplift and denudation across the Tibetan Plateau, it is crucial to integrate chronological data from various studies. Recent research has employed techniques such as U-Pb dating of detrital zircon, thermochronology, and paleontological evidence to establish age constraints on sediment deposition and tectonic events.

For instance, studies utilizing detrital zircon geochronology in the Sichuan Basin have revealed significant provenance shifts that correspond with periods of tectonic activity. These findings can be cross-referenced with similar studies in adjacent regions, such as the Yidun Terrane and Lhasa Terrane, which provide complementary data on sedimentary processes and uplift histories.

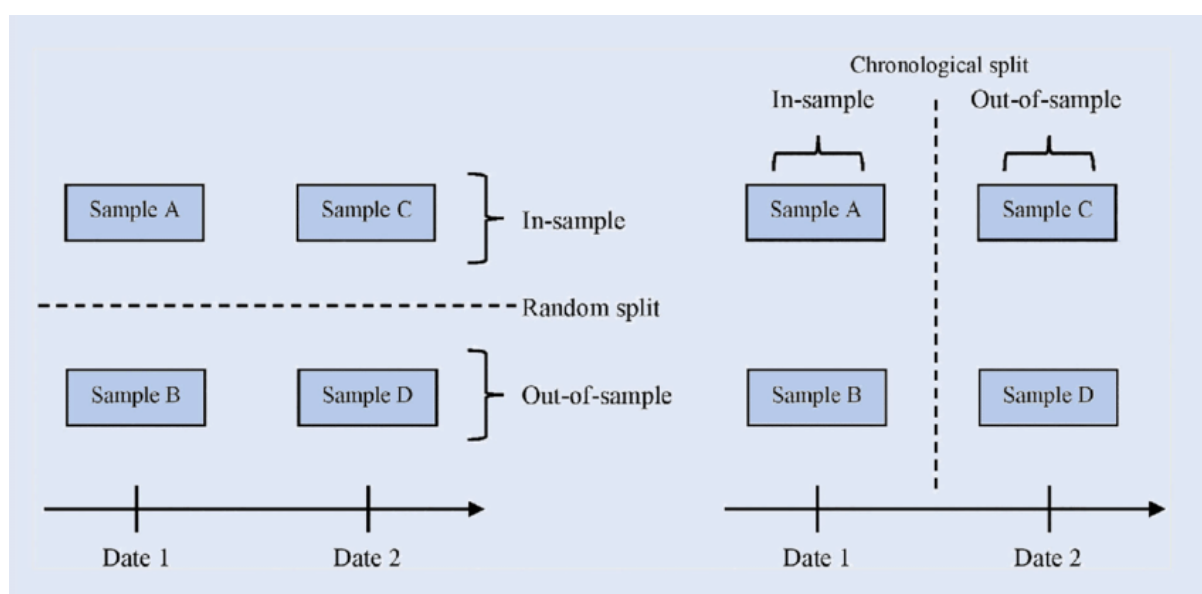


Figure 3. Chronological Data.

In particular, thermochronology has proven invaluable in constraining the timing of denudation events. For example, research indicates that rapid denudation phases occurred in various parts of the Tibetan Plateau during key geological intervals, including the late Jurassic and Cretaceous periods. By synthesizing these datasets, researchers can establish a more detailed chronological framework that highlights regional variations in uplift and erosion.

5. 2. Correlating Geological Events

The constructed timeline not only sheds light on local geological processes but also correlates with major geological events that have influenced the Tibetan Plateau's evolution. One significant event is the India-Asia collision, which began approximately 50 million years ago. This collision is widely regarded as a primary driver of tectonic uplift across the plateau, leading to substantial changes in topography and sedimentation patterns.

Research suggests that prior to this collision, significant uplift may have already begun in certain regions of Tibet during the late Jurassic to early Cretaceous periods. This pre-collision uplift is evidenced by sedimentary records indicating elevated landforms and substantial erosion rates. By integrating this information into the broader timeline, researchers can better understand how early tectonic activity set the stage for subsequent geological developments related to the India-Asia collision.

5. 3. Implications for Understanding Uplift Mechanisms

Understanding the chronological framework also allows for a deeper exploration of the mechanisms driving uplift across different regions of the Tibetan Plateau [32]. For example, while crustal shortening due to plate collision is a well-documented mechanism, other processes such as edge-driven convection and mantle delamination may also play significant roles in certain areas. By correlating timing with specific geological features, such as changes in sediment composition or patterns of erosion, researchers can discern how these mechanisms interact over time.

Additionally, this integrated approach enables researchers to identify potential feedback loops between tectonic activity and surface processes. For instance, rapid denudation resulting from uplift may lead to increased sediment supply to adjacent basins, which in turn influences further tectonic activity through sediment loading effects.

Establishing a comprehensive chronological framework is vital for understanding the complex interplay between uplift and denudation processes across the Tibetan Plateau. By integrating data from various studies and correlating these findings with major geological events like the India-Asia collision, researchers can develop a nuanced understanding of how tectonic mechanisms have shaped this unique landscape over time. This framework not only enhances our knowledge of local geological histories but also contributes to broader discussions about mountain-building processes globally. Future research efforts should continue to refine this timeline by incorporating new data sources and methodologies, ultimately enriching our understanding of one of Earth's most dynamic regions.

6. IMPLICATIONS FOR UNDERSTANDING TIBETAN PLATEAU EVOLUTION

The evolution of the Tibetan Plateau is a complex narrative shaped by various geological, climatic, and ecological factors [33]. Comparative studies of sedimentary records from regions

like the Sichuan Basin, Yidun Terrane, and Lhasa Terrane have profound implications for our understanding of this evolution, particularly regarding tectonic processes and their impact on the landscape.

6. 1. Enhancing Understanding of Regional Tectonics

One of the primary implications of these comparative studies is the enhanced understanding of regional tectonics. By examining sediment provenance and uplift mechanisms across different terranes, researchers can identify how local geological histories contribute to the broader tectonic framework of the Tibetan Plateau. For instance, the Sichuan Basin's rapid denudation linked to crustal shortening provides insights into how tectonic forces have shaped sedimentary processes in adjacent regions. Similarly, contrasting sediment sources in the Yidun and Lhasa terranes highlight the varied responses of these areas to tectonic stresses [34-37]. This knowledge is crucial for developing more accurate models of how the plateau has evolved over time.

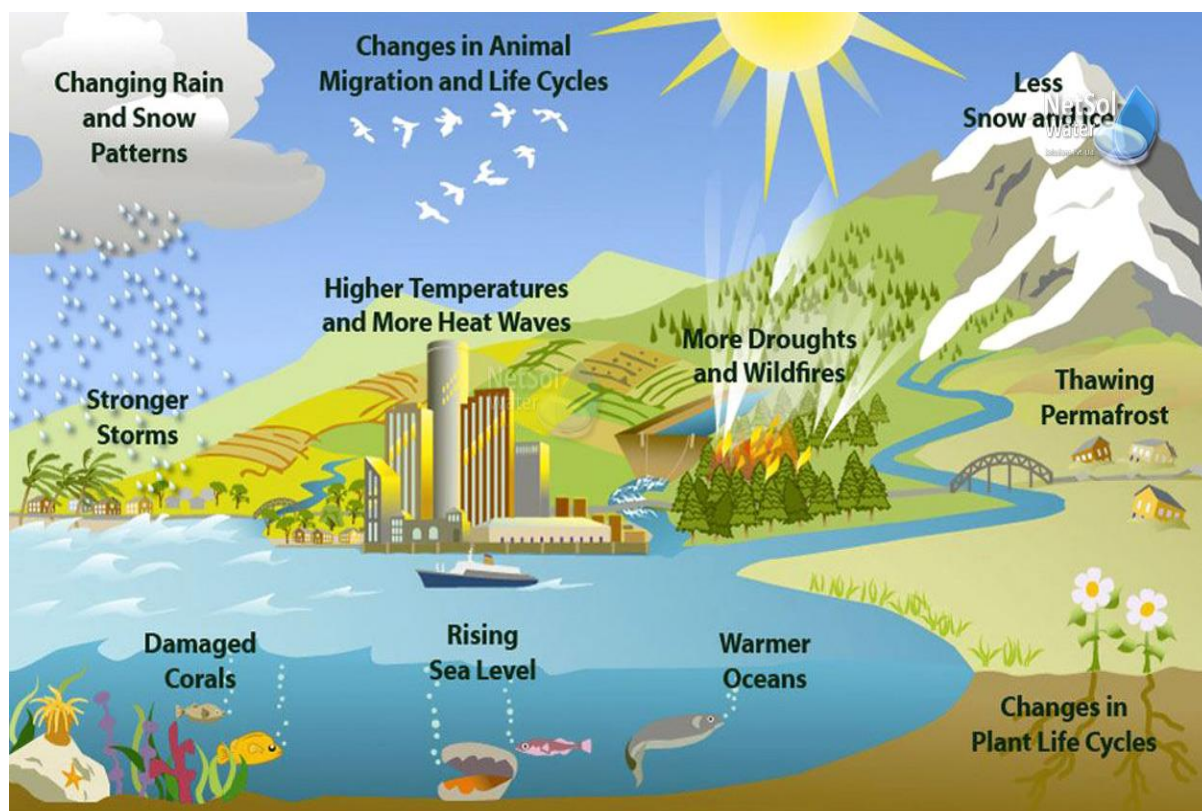


Figure 4. Climate and Ecology: Menonimus.org

6. 2. Insights into Sedimentary Processes

Comparative analyses also shed light on sedimentary processes that have occurred throughout the plateau's history. The interplay between uplift and erosion is a key theme in understanding how sediments are transported and deposited in various basins. For example, the findings from the Sichuan Basin indicate that significant erosion during periods of tectonic

uplift resulted in substantial sediment supply to adjacent areas [38-41]. This relationship underscores the importance of considering sedimentary dynamics when studying the geological evolution of mountainous regions.

Moreover, understanding these processes can help explain patterns of sedimentation observed in other parts of Tibet, revealing how changes in climate and tectonics have influenced sedimentary environments over geological timescales.

6. 3. Impacts on Climate and Ecology

The Tibetan Plateau plays a crucial role in influencing Asian climate systems, particularly through its effects on monsoon patterns (Fig. 4) [42-44].

The evolution of its topography has direct implications for regional climate dynamics. As the plateau has risen and changed shape over millions of years, it has altered atmospheric circulation patterns that affect precipitation distribution across Asia [45-47].

Comparative studies contribute to this understanding by linking geological changes to climatic outcomes. For instance, as rapid denudation occurs due to tectonic uplift, increased rates of weathering can lead to changes in soil composition and vegetation patterns. Such shifts have cascading effects on local ecosystems and biodiversity. Understanding these interactions is essential for predicting how ongoing geological processes might influence future climatic conditions in Asia.

6. 4. Future Research Directions

The insights gained from comparative studies open up numerous avenues for future research. There is a need for more extensive investigations into underexplored regions within Tibet that could provide additional data on sedimentary processes and tectonic activity. Employing advanced geochronological techniques and integrating paleoclimatic data can further refine our understanding of how these factors interact over time.

Additionally, interdisciplinary approaches that combine geology with ecology and climate science will be essential for developing a holistic understanding of the Tibetan Plateau's evolution. Such integrative research can help elucidate complex feedback mechanisms between tectonics, climate change, and ecological responses.

This comparative studies significantly enhance our understanding of Tibetan Plateau evolution by providing insights into regional tectonics, sedimentary processes, and their implications for climate and ecology. By examining how different regions respond to tectonic forces and environmental changes, researchers can develop more nuanced models that capture the complexity of this dynamic landscape. As we continue to explore these relationships through interdisciplinary approaches, we move closer to unraveling the intricate history of one of Earth's most significant geological features.

7. CONCLUSIONS

The study "Mid-Cretaceous Rapid Denudation of Eastern Tibetan Plateau: Insights from Detrital Records at the Southwestern Corner of Sichuan Basin" provides critical insights into the complex geological history of the Tibetan Plateau during a pivotal period in Earth's history. By employing a multi-proxy approach that integrates detrital zircon geochronology, heavy

mineral analysis, and paleocurrent studies, the authors have effectively elucidated the sediment provenance and tectonic mechanisms that shaped this dynamic landscape.

Through comparative analyses with adjacent regions such as the Yidun and Lhasa terranes, this research highlights the intricate interplay between tectonic uplift and sedimentary processes across the plateau. The findings reveal significant shifts in sediment sources and patterns of denudation that correlate with active tectonic events, underscoring the importance of understanding local geological histories within a broader regional context.

Moreover, this study emphasizes the implications of these geological processes for understanding climate dynamics and ecological responses in Asia. The Tibetan Plateau's evolution has profound effects on atmospheric circulation and monsoon patterns, illustrating how geological changes can influence climatic conditions over vast distances.

As we move forward, it is essential to continue exploring the Tibetan Plateau through interdisciplinary approaches that integrate geology, climate science, and ecology. Future research should focus on underexplored regions to further refine our understanding of sedimentary processes and tectonic activity. By doing so, we can develop a more comprehensive picture of how the Tibetan Plateau has evolved over time and its role in shaping not only its immediate environment but also broader climatic systems.

In conclusion, this paper not only contributes to our understanding of mid-Cretaceous denudation processes but also sets the stage for future investigations into the complex interactions between tectonics, sedimentation, and climate in one of Earth's most significant geological features. The insights gained from this research are invaluable for unraveling the intricate history of the Tibetan Plateau and its ongoing evolution in response to dynamic geological forces.

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