Multi-sphere Interactions of the Qinghai-Tibet Plateau and Their Resource and Environmental Effects: Postprint

Authors: Institute of Tibetan Plateau Research, Chinese Academy of Sciences; Institute of Geology and Geophysics, Chinese Academy of Sciences

Date: 2017-02-08T00:00:00+00:00

Abstract

The uplift of the Tibetan Plateau has altered the Earth's planetary wind system, transformed the Asian climate, and changed China's living environment. The multi-sphere interactions among the six major spheres of the Tibetan Plateau—the lithosphere, hydrosphere, cryosphere, biosphere, anthroposphere, and atmosphere (Fig. 1)—serve as the driver of all these changes. These multi-sphere interactions have formed the "water tower" for more than ten major rivers in Asia, benefiting the Asian people, while also causing frequent natural disasters such as earthquakes that affect human survival. The multi-sphere interactions following the collision and uplift of the Tibetan Plateau constitute one of the focal points of Earth system science research.

Full Text

1. Project Background and Significance

The Qinghai-Tibet Plateau Special Project (hereinafter referred to as the "Plateau Project") has established the following scientific objectives: to investigate the fundamental characteristics, processes, and mechanisms of multi-sphere interactions on the Qinghai-Tibet Plateau, achieving new scientific breakthroughs in the timing and mode of India-Eurasia collision, paleoaltimetry of plateau uplift, and the influence of westerlies and monsoons and their environmental effects. These advances aim to elevate China's earth system science research to a world-leading position while making important contributions to the social and economic development of the Qinghai-Tibet region. Based on these scientific objectives, the project has established three major research programs encompassing 19 topics: (1) Evolution of the Neo-Tethys Ocean and paleogeographic reconstruction of the southern plateau; (2)

Neo-Tethys oceanic crust expansion and chromite mineralization; (3) Formation of the Gangdese arc and Cu-Mo mineralization; (4) Timing, mode, and process of India-Eurasia continental collision; (5) Plateau boundary expansion processes and mechanisms; (6) Composition, thermal state, and evolution of deep plateau lithosphere; (7) Lithospheric structure probing and crust-mantle interaction in northern Tibet; (8) Comparative study of deep lithospheric structure between Iran and the Tibetan Plateau; (9) Quantitative estimation of paleoaltitude across different periods; (10) Cenozoic intracontinental deformation and remote effects on the northern plateau margin; (11) Development history of major rivers on the plateau's eastern side and their relationship to plateau uplift; (12) Plateau uplift, continental erosion-weathering, and environmental effects; (13) Influence of plateau uplift on Asian interior aridification and monsoon evolution; (14) Numerical simulation of plateau uplift environmental effects; (15) Spatial patterns of paleoclimate and environment during characteristic periods since the Last Glacial Maximum and their multi-sphere interaction processes; (16) Phase transformation processes of modern water bodies between different spheres and their impacts; (17) Model development and application for surface environment response to climate change; (18) Sensitivity of key surface process elements to global warming and their environmental impacts; and (19) Environmental effect evaluation and optimization recommendations for ecological security barrier construction. Participating institutions include 12 CAS research institutes and 12 universities.

The Plateau Project officially launched in October 2012, with Academician Yao Tandong (Director of the Institute of Tibetan Plateau Research, CAS) and Academician Wu Fuyuan (Deputy Director of the Institute of Geology and Geophysics, CAS) serving as chief scientists. The project is hosted by the CAS Center for Excellence in Tibetan Plateau Earth Sciences, the Institute of Tibetan Plateau Research, and the Institute of Geology and Geophysics [FIGURE:1].

2. Breakthrough Research Results

After more than three years of intensive research, the project had published 530 SCI papers by the end of 2015, including over 20 articles in high-end journals such as 2 *Nature* (Article), 1 *Science*, 7 *Nature Communications*, 3 *Nature Climate Change*, 1 *Reviews of Geophysics*, and 8 *PNAS*. The breakthrough progress in multi-sphere interaction research has yielded three innovative insights: the collision-uplift trigger point, the remote effect diffusion source, and the westerly-monsoon interaction chain.

First, the project identified the spatial point of initial India-Eurasia collision in the central region and the temporal point at 65 Ma. Research reveals that the Indian and Eurasian plates first collided in the central region approximately 65 million years ago, followed by collisions in the east (Myanmar at 49 Ma) and west (Pakistan at 46 Ma) [FIGURE:2]. Following collision, continental lithosphere subducted piecemeal beneath the plateau, doubling crustal thickness and triggering melting. The molten lower crust formed channel flow that migrated toward the southeastern plateau. Both the Kunlun Mountains and the Longmen Shan region (site of the Wenchuan earthquake) are located within this channel flow zone, providing new insights into the deep causes of major earthquakes in Tibet, Wenchuan, and Nepal. These findings have garnered significant international attention, with *Nature News* featuring special coverage.

Second, the project discovered that the Tibetan Plateau serves as a diffusion source for remote effects linking the geosphere and biosphere. Research indicates that the central plateau reached an altitude of 2,500–3,200 meters around 30 Ma. This uplift process fundamentally established China's west-high/east-low topographic pattern, enabling the Yangtze River to flow eastward to the sea by 23 Ma. The same uplift process caused primate evolution in Asia to diverge from that in Africa-Arabia, offering a new explanation for why humans originated in Africa rather than Asia [FIGURE:3]. The plateau approached its modern elevation around 4 Ma, entering a periglacial environment and becoming a diffusion source for global Quaternary ice-age fauna. Species now inhabiting cold regions—such as the arctic fox, woolly rhinoceros, snow leopard, and argali—first appeared on the Tibetan Plateau before radiating to surrounding areas. These results have generated substantial international impact, with *Nature* and *Science* both publishing special features on the findings.

Third, the project discovered that the modern westerly-monsoon interaction system produces chain-reaction environmental effects following plateau formation. Research reveals that the plateau experienced two major transitions from westerly-dominated to monsoon-dominated climates at 16.5 ka (post-Last Glacial Period) and 4 ka (mid-Holocene), establishing the modern westerly-monsoon interaction system. This system exhibits three modes: monsoon mode, westerly mode, and transitional mode [FIGURE:4]

. These three modes create chain-reaction environmental effects: they first produce a distinct north-south precipitation seesaw pattern across the plateau, with opposite precipitation characteristics in northern and southern regions. This seesaw process subsequently influences glaciers, lakes, and vegetation patterns, creating clear north-south regional differences. The chain-reaction environmental effects of westerly-monsoon interactions are scientifically significant for understanding environmental change characteristics and impacts in high-altitude plateau regions, have broad implications for understanding the plateau's extensive environmental effects, and provide practical guidance for regional social development. The research has generated major international attention, with *Nature* and *Science* publishing series of special reports. The work on westerly-monsoon chain-reaction environmental effects ranks in the top 0.01% of international impact, placing the research team in the leading position of the "Top 10 Geoscience Frontiers of 2015" reported by Thomson Reuters.

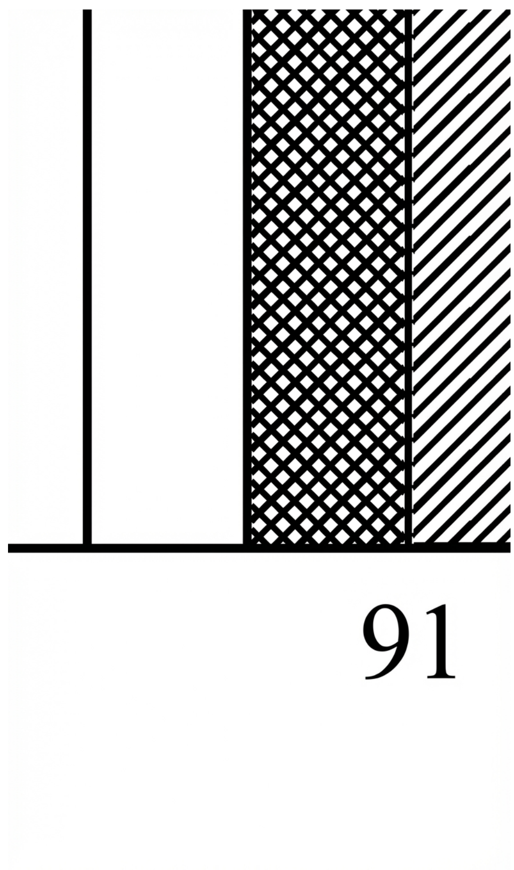

Figure 1: Figure 5

3. Major Social Benefits

The research has also generated significant societal impacts through policy advisory reports, white papers, and scientific assessments of environmental changes on the Tibetan Plateau. First, a completed advisory report received high-level attention from the Tibet Autonomous Region Party Committee, providing scientific support for Tibet's medium- and long-term development plan for 2015–2030. Second, the research served national diplomatic strategy by contributing to the State Council Information Office's white paper *Development and Progress of Tibet*. Utilizing research findings on the plateau's ecological environment provided robust scientific support for demonstrating Tibet's ecological civilization construction, effectively functioning as a think tank. The white paper generated positive and strong responses domestically and internationally, producing excellent external publicity results and strongly supporting the Party and state's overall work. Third, the *Scientific Assessment of Environmental Changes on the Tibetan Plateau*, compiled based on project findings, received high praise from President Xi Jinping, who specifically cited the report's research results in his important speech at the Sixth Tibet Work Forum as the scientific foundation for instructions on ecological and environmental protection of the Qinghai-Tibet Plateau (August 2015).

During the project implementation period, the program cultivated a cohort of outstanding young talents (including recipients of the National Science Fund for Distinguished Young Scholars, Excellent Young Scientists Fund, Changjiang Scholars Program, and various other prestigious talent programs). In the 2015 list of China's Most Cited Researchers released by Elsevier in January 2016, eight scientists from the Plateau Project were included.

4. Future Deployment for Qinghai-Tibet Plateau Research, Talent Cultivation, and Related Areas

During the 13th Five-Year Plan period, the Plateau Project will rely on the CAS Center for Excellence in Tibetan Plateau Earth Sciences to conduct in-depth research on plateau sphere evolution and its remote effects.

4.1. Sphere Interactions from Oceanic to Continental Subduction

The India-Eurasia plate collision represents the most important orogenic event in Earth's history over the past 500 million years, forming the uplift of the Tibetan Plateau and generating strong remote tectonic effects across vast Asian regions. Traditional plate tectonic theory considers continental collision as the termination of the Wilson Cycle. However, since the collision, the Indian continent has continued converging northward, causing intense intracontinental shortening, extrusion, and rotation. The Tibetan Plateau and surrounding blocks have experienced strong deformation, metamorphism, magmatism, and mineralization since collision. The continued subduction of Indian continental lithosphere has also triggered intense exchange of crust-mantle materials and energy, leading to reorganization of lithospheric material and structure. Building on previous progress, the key scientific question for future research is: What is the fate of subducting plates after collision? Main research content includes: probing subduction structures of different lithospheric properties, subducting plate behavior and plate-mantle interface processes, magmatic responses to oceanic and continental lithosphere subduction, comparison of mineralization between oceanic and continental subduction systems, and multi-sphere interactions in oceanic-continental subduction systems.

4.2. Plateau Uplift Process and Its Remote Environmental Effects

Cenozoic uplift of the Tibetan Plateau has profoundly impacted shallow surface spheres. China's macro-scale topographic pattern differed significantly before and after plateau uplift. Prior to uplift, China inherited the basic topographic and climatic pattern of the Cretaceous, with terrain generally sloping westward. However, since the India-Asia continental collision, China's originally westward-sloping terrain gradually evolved to slope eastward, eventually forming large east-flowing river systems. The elevated plateau also affected the atmosphere. Before plateau uplift, the Northern Hemisphere was controlled by zonal circulation without an Asian monsoon. After plateau uplift, the topographic barrier "amplified" land-sea thermal contrasts, strengthening the Asian summer monsoon and altering Northern Hemisphere atmospheric circulation. Plateau uplift also enhanced shallow surface erosion and weathering, continuously exposing and fracturing fresh bedrock, accelerating chemical weathering, consuming more atmospheric CO_2, and contributing to Cenozoic global cooling. The dual effects of topographic barrier and climate change also influenced flora and fauna succession, significantly impacting the biosphere. Therefore, plateau uplift has important effects on Asia's macro-scale geomorphic pattern and, through sphere interactions, significantly influences Asian and global climate at million-year and orbital timescales. The key scientific question for future research is: How does the plateau uplift process regulate Asian geomorphic patterns and regional to global climate at different timescales? Main research content includes: paleogeographic patterns during key periods and their influence on atmospheric circulation, comparison of major Cenozoic geological-environmental events in typical tectonic units, and modulation of different-scale climate changes by plateau uplift processes.

4.3. Spatiotemporal Variations in Surface Multi-sphere Interactions and Their Response to Westerlies and Monsoons

After Tibetan Plateau uplift, westerlies were deflected and Indian monsoon intensity strengthened. Global change strongly impacts plateau surface processes through modifications of these two circulation systems and their associated climatic conditions, which in turn affect broader climate environments through land-atmosphere interactions. Previous research has revealed the history of climate and environmental changes in westerly and monsoon-influenced regions and characteristics of modern surface element changes. However, both climate change and surface element alterations result from surface sphere interactions, requiring further understanding of their interconnections, internal mechanisms, and broader impacts. The key scientific question for future research is: How does the surface system respond to westerly-monsoon variations and influence regional environments? Main research content includes: water vapor source tracing and atmospheric circulation change mechanisms, surface processes and their impacts on surrounding climate change, surface sphere interaction processes and hazards, and spatiotemporal variations and future scenarios of environmental change.

Currently, relying on Plateau Project implementation, the program has assembled the most innovative Tibetan Plateau research talents in China around key fields and directions, establishing and strengthening the talent team of the Center for Excellence. During the 13th Five-Year Plan period, the project will consider recruiting internationally outstanding Tibetan Plateau researchers to further expand team capacity, striving to establish an innovation talent highland in earth science research and contribute to the CAS "Pioneer Initiative."

Expert Commentaries

Lawrence Flynn, Researcher at the Department of Human Evolutionary Biology and Peabody Museum of Archaeology and Ethnology, Harvard University, USA. Primarily engaged in Asian vertebrate fossil research, with long-term focus on terrestrial sediments and mammalian fossils in the Siwalik Group along the southern margin of the Tibetan Plateau and the Indian-Pakistani subcontinent, as well as extensive collaborative research on Cenozoic basins within China around the plateau. He has published over 140 academic papers (including monographs), including multiple *Nature* papers.

This research is crucial for understanding the dynamic characteristics of the Qinghai-Tibet Plateau, which can only be accomplished within the framework of Earth's evolutionary history. Geological data, atmospheric circulation and sediment distribution (water and air) data, and paleontological data play decisive roles in answering scientific questions. Studying this aspect of Earth's characteristics is of great significance to humanity. Global ecosystems are extremely fragile, and this research can provide information support for us to cope with harsh regional living conditions—the project's research is not only extremely important but also very necessary.

Yongwei Sheng, Tenured Professor in the Department of Geography, University of California, Los Angeles (UCLA), USA. His main research directions include remote sensing, photogrammetry, and geographic information systems and their applications in resource management, environmental analysis, and global change research. Professor Sheng has published over 40 papers in major international professional journals, including three papers in *Science*. His current research projects include 3D information technology in geographic information science, 30-year water resource changes in the Arctic region, and paleolake and modern lake and vegetation ecological environment evolution studies in cold regions such as the Tibetan Plateau.

The Qinghai-Tibet Plateau possesses unique landscapes on Earth, and plateau research represents one of the frontier scientific fields led by Chinese scientists. The project's integrated research emphasizes multi-sphere interactions across timescales, further strengthening original research led by China's top scientists. This special project is expected to achieve theoretical breakthroughs and will promote human understanding of the plateau from multiple perspectives. The research results will have major impacts on resource development and environmental assessment in the plateau and surrounding regions.