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Glacial geomorphology and paleoglaciation patterns in Shaluli Shan, the southeastern Tibetan Plateau — Evidence for polythermal ice cap glaciation

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ABSTRACT

Glacial geomorphological mapping from satellite imagery and field investigations provide the basis for a reconstruction of the extent and style of glaciation of the Shaluli Shan, a mountainous area on the southeastern Tibetan Plateau. Our studies provide evidence for multiple glaciations, including the formation of regional ice caps and valley glaciers. The low-relief topography within the Shaluli Shan, the Haizishan Plateau, and Xinlong Plateau display zonal distributions of glacial landforms that is similar to those imprinted by Northern Hemisphere ice sheets during the last glacial cycle, indicating the presence of regional, polythermal ice caps. Abundant alpine glacial landforms occur on high mountain ranges. The pattern of glaciated valleys centered on high mountain ranges and ice-scoured low relief granite plateaus with distinctive patterns of glacial lineations indicate a strong topographic control on erosional and depositional patterns by glaciers and ice caps. In contrast to the Shaluli Shan, areas farther north and west on the Tibetan Plateau have not yielded similar landform evidence for regional ice caps with complex thermal basal conditions. Such spatial differences across the Tibetan Plateau are the result of variations in climate and topography that control the extent and style of glaciations and that reinforce the importance of detailed geomorphological mapping for understanding paleoclimate variations and characteristics of former glaciations.

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1. Introduction

Considerable controversy and uncertainty have surrounded reconstructions of the extent, timing, and landscape impact of Tibetan Plateau glaciations. Resolving this controversy is important because of the central role of glaciation in paleoclimate reconstructions and geological evolution models. In some of the earliest studies, Hedin (1909, 1922) and Ward (1922, 1934) argued against the presence of a former ice sheet on the Tibetan Plateau mainly because of the lack of till, glacial sediments typically deposited by continental ice sheets elsewhere. Huntington (1906), Trinkler (1930), and Sinitsum (1958), on the other hand, argued for the former presence of a continental-scale ice sheet in this region based on inferred glacial origins of large lakes on the plateau. A series of major expeditions to the Tibetan Plateau conducted by Chinese scholars in the 1950s, 1960s, and 1970s produced a large number of papers that presented evidence for glacier expansions during the Pleistocene characterized by ice caps, trellis valley glaciers and piedmont glaciers, and these papers contradicted the ice sheet hypothesis (Luo and Yang, 1963; Cui, 1964; Shi and Liu, 1964; Li, 1975; Zheng and Shi, 1976; Cui, 1979; Zheng and Li, 1981; Shi et al., 1982; Li and Xu, 1983; Li et al., 1983; Shi et al., 1986). In the 1980s and 1990s, Kuhle (1986, 1987, 1988, 1990, 1991, 1995) resurrected the ice sheet hypothesis and argued for a significant plateau-wide ice sheet during the Last Glacial Maximum (LGM). This stimulated a renewed interest for studies of glacial chronologies in key locations. These studies indicated that a variety of deposits and landforms had been misinterpreted as glacial landforms (Derbyshire et al., 1991; Shi, 1992; Zheng and Rutter, 1998). Thus, most researchers now recognize that expansions of ice during the Pleistocene were limited, predominantly as glaciers and ice caps radiating from the highest mountains, and that the timing of these events sometimes shows a mismatch with the northern hemispheric ice sheet records (Zheng, 1989; Rutter, 1995; Owen et al., 2002, 2005; Zheng et al., 2002; Lehmkuhl and Owen, 2005; Shi et al., 2005; Heyman et al., 2009, 2011a, 2011b). The most comprehensive reconstruction of glacial extent on the Tibetan Plateau indicates that at most approximately 0.5×10^6 km^2 was covered by glacier ice (Li et al., 1991).

Although several comprehensive assessments of existing reconstructions provide an overall picture of Quaternary glaciations (Li et al., 1991; Shi et al., 1992, 2005), much work is still required to systematically determine the extents, timing, and impacts of glacial advances, particularly as the responses of glaciers to past climate change seem to have varied in their timing and extent across the Tibetan Plateau

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(Owen et al., 2005, 2008). Most reconstructions have focused on the use of individual landforms, primarily moraines and glacial valleys, to delineate glacial extent (Cui, 1981a; Derbyshire et al., 1991; Lehmkuhl and Liu, 1994; Zheng and Rutter, 1998; Zheng, 2000, 2001; Zheng et al., 2002; Owen et al., 2003; Klinge and Lehmkuhl, 2004; Zhou et al., 2007; Wang et al., 2011), while fewer studies have examined broader suites of glacial landforms (Cui, 1981b; Zheng and Ma, 1995). However useful these studies are, detailed and consistent studies of the pattern of glaciations from glacial landforms are lacking for large parts of the Tibetan Plateau.

To produce regional reconstructions of glacial extent based on detailed glacial geomorphology and chronology for large regions of the Tibetan Plateau, an international team has been conducting three consecutive projects focused on the Bayan Har Shan (Heyman et al., 2008), Tanggula Shan (Morén et al., 2011), and Shaluli Shan (Fu et al., 2012) (Fig. 1). This includes detailed and consistent mapping work that provides a basis for an analysis of the types and patterns of landforms aimed at understanding the extent and dynamics of the glaciers that produced them. For example, studies of the landforms of the Bayan Har Shan (Heyman et al., 2008, 2009; Stroeven et al., 2009) have shown that there were ice field- and valley glacier-style glaciations during the Pleistocene. However, they found no evidence that the area was ever covered by a Huang He Ice Sheet as proposed by Zhou and Li (1998). Given the vast area of the Plateau, more detailed and consistent mapping is required for other areas before a detailed picture can emerge of the extent and pattern of Quaternary glaciation on the Tibetan Plateau.

Building on detailed geomorphological mapping (Fu et al., 2012), here we examine the types and patterns of glacial landforms in the Shaluli Shan region, in particular the landform patterns across the Haizishan Plateau. We interpret patterns of glacial lineations, scoured terrain, and relict areas in terms of basal ice thermal condition, and discuss why this region displays different landform assemblages than other areas of the Tibetan Plateau that have been studied in similar detail.

2. Physical setting

The study area of 104,000 km^2 is situated on the southeastern margin of the Tibetan Plateau and includes the Shaluli Shan (Shan = mountain range) and a series of other NW–SE trending mountain ranges (Fig. 1). These mountains compose the eastern part of Hengduan Mountain, which is one of the most prominent ranges of the Tibetan Plateau. Whereas uplift of the Tibetan Plateau began around 50 million years ago (Harrison et al., 1992), based on thermochronological data it has been argued that the southeastern Tibetan Plateau experienced rapid uplift during the late Cenozoic (Clark et al., 2005; Ouimet et al., 2010). The bedrock geology consists mainly of Triassic flysch of the Songpan-Garze terrane and Triassic volcanic and sedimentary rocks, intruded by Jurassic plutons (Ouimet et al., 2010). The two major granite plutons underlie two very distinctive geomorphological units in this area, the Haizishan Plateau and the Xinlong Plateau.

The Shaluli Shan area includes both high relief mountains and relatively low relief upland landscapes. The mountains are deeply incised by major river branches, while low relief landscapes in between display little incision by small tributaries. The plateau-elevation primarily ranges between 3500 and 4800 m above sea level (asl), with the highest peak reaching 7556 m asl (Mt. Gongga). The major rivers cut deep into the high relief mountains — in some cases down to 2000 m below the mountain peaks creating a local relief of up to 5000 m over a 15-km distance.

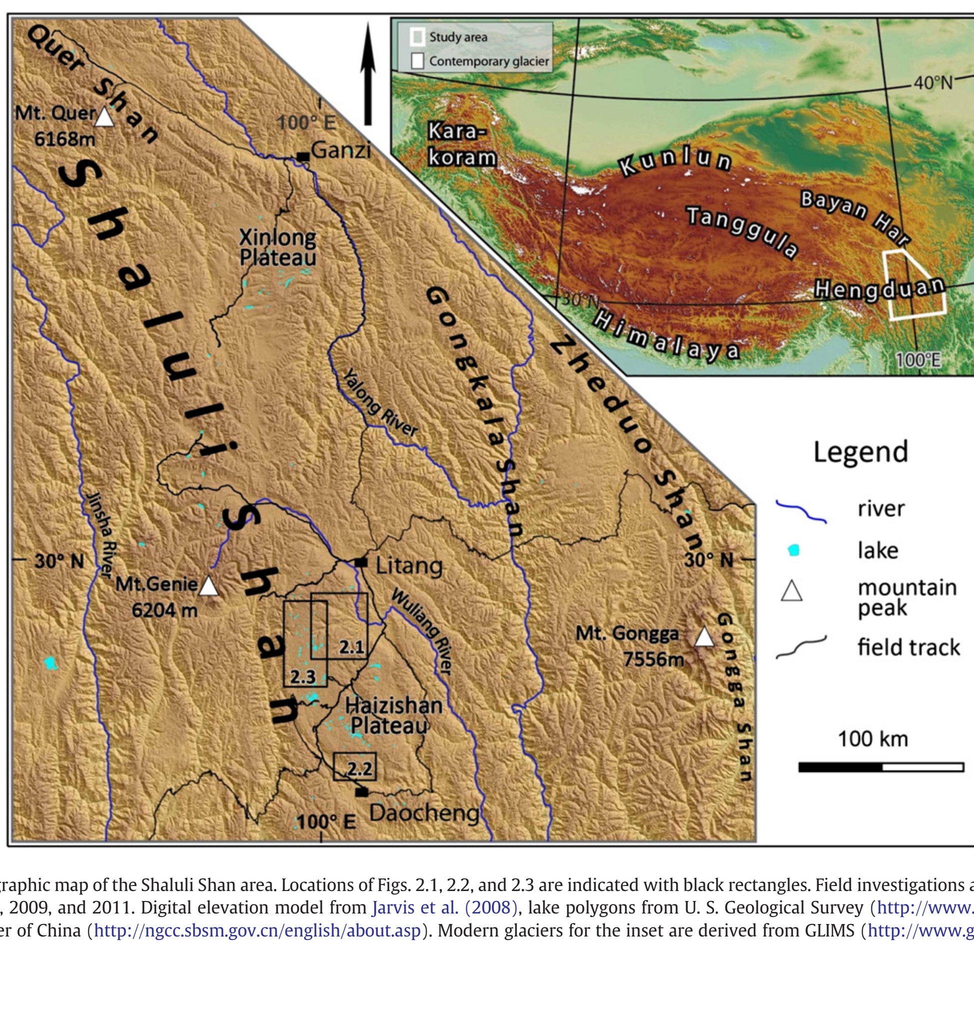

Fig. 1. Location and topographic map of the Shaluli Shan area. Locations of Figs. 2.1, 2.2, and 2.3 are indicated with black rectangles. Field investigations along roads and in key areas were carried out in 2008, 2009, and 2011. Digital elevation model from Jarvis et al. (2008), lake polygons from U. S. Geological Survey (http://www.usgs.gov/), and rivers from National Geomatics Center of China (http://ngcc.sbsm.gov.cn/english/about.asp). Modern glaciers for the inset are derived from GLIMS (http://www.glims.org).

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