Geomorphology of the Huang He ice sheet area: towards a reconstruction of the glacial history of the northeastern Tibetan Plateau

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Recent terrestrial cosmogenic nuclide (TCN) studies on end moraines of the Tibetan Plateau have yielded a first synthesis of the timing of mountain glacier and ice field maximum extents at discrete times in the past. Although these allow important constraints on the presence of expanded ice on the plateau, they don't address the question of the presence of areally more extensive ice sheet configurations where mountain ice complexes from discrete mountain blocks coalesce to form larger bodies. Two ice sheets hypothesised to have covered parts of the Tibetan Plateau are the Tibetan ice sheet and the areally much more restricted Huang He ice sheet. In this study we have focussed on the hypothesised Huang He ice sheet area in the headwaters of the Huang He and Yangtze rivers on the north-eastern margin of the Tibetan Plateau.

Two mountain blocks from which ice might have emanated to inundate the plateau surface around it and form the ice sheet are the marginally-located Anyemaqen and centrally-located Bayan Har Mountains. Of these the Anyemaqen is located closer to the edge of the plateau, is higher, wetter, and is ornamented with glaciers today, which, according to TCN studies have been more extensive during marine oxygen isotope stages 3, 2, and 1.

Using Landsat 7 ETM+ satellite imagery we have mapped the glacial geomorphology of the entire hypothesised Huang He ice sheet area (50,000-70,000 km^2) and concentrated our TCN field sampling to its core area, the Bayan Har Mountains. The area displays widespread morphological evidence of glacial erosion and deposition, particularly around the higher mountain blocks. The erosional landforms include large-scale glacial troughs, U-shaped valleys and occasional lake basins, and small-scale lateral meltwater channels. The depositional landforms include primarily lateral and end-moraines, but also hummocky moraines and drumlins. Field inspection has yielded observations of tills and erratic boulders. Taken together, these traces comprise an impressive record of multiple large-scale erosional events as witnessed by cross-cutting relationships of glacial valleys and multiple glacier advances through the Bayan Har Mountain valleys, some of which terminated onto the plateau surface, by the presence of suites of end-moraines and associated meltwater traces.

The mapping exercise thus far has established a clear patchiness to the erosional imprint of ice in the uplands comprising the Huang He ice sheet area. Although the integrated imprint of erosion is clear and displays a pattern of topographically-forced selective linear erosion, the rates of glacial landscape change in the absence of TCN measurements remains unknown.

We note that except for the arguable presence of tills and the reported, but not confirmed, presence of erratics beyond the mountain fronts, we have not been able to establish firm evidence of ice coverage on the intervening plateau surfaces. Rather, many areas display a distinct non-glacial morphology with well-developed fluvial valley systems and basins infilled with alluvial deposits. This casts some doubt on the concept of the Huang He ice sheet, although one may argue that, if of considerable age, few glacial traces may have survived degradational processes. Moreover, we conclude that the break in slope between the youthful steep fluvial landscapes of the Huang He and Yangtze rivers and the relict gentle sloping surface of the Tibetan Plateau almost entirely coincides with the outline of the Huang He ice sheet bordering these rivers. This *could* be used to further question the reality of the Huang He ice sheet or, if indisputable further evidence can be uncovered in the years to come, the coincidence of borders *could* indicate that the ice sheet was larger but that evidence for this is now flowing down the rivers.

Finally, an ambitious TCN and OSL sampling campaign in the Bayan Har Mountains region with our colleagues from the USA (Caffee, Harbor, Li) and China (Zhou, Liu, Ma) will likely shed light on the timing of glacial advances through the dating of end moraines, erratics and till stratigraphies and establish contemporary landscape catchment erosion rates through the analysis of river bank sediment TCN concentrations.