Ngozumpa Glacier Caves Research Project 2005

Report

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The aim of this expedition was to conduct the first scientific investigation of englacial and subglacial conduits (ice caves) in the Khumbu Himal, Nepal Himalaya. Previous work in the region has shown that such caves exert a very important control on the evolution of the glacier surface, by determining the location of sinkholes and collapses (which act as the nuclei for supraglacial ponds and lakes) and by triggering the drainage of existing lakes. Despite their importance, however, nothing was known of their character and distribution, or the factors that determine their formation and evolution. In November and December of 2005, Doug Benn, Jason Gulley, Endre Gjermundsen and Steve Keene spent six weeks in the Khumbu Himal, exploring and mapping on five glaciers (Image. 1). The caves ranged in altitude between 4900m and 5300m, and replace Peru¹s Qaqa Mach'ay at 4930 m as the highest surveyed caves in the world. The longest cave surveyed was 905m, falling just short of the world record of 1040m. We are confident that this can be exceeded in a second expedition to the glacier in November 2006.

Previous experience suggested that by mid November melting should have ceased on the glaciers, allowing safe access to their internal drainage system. On the approach, via Lukla and Namche, it became apparent that the late autumn season in 2005 was unusually warm, and considerable quantities of meltwater were still being discharged in the Dudh Khosi. It was therefore decided to spend the acclimatization period reconnoitering glaciers in the Imja and Khumbu catchments prior to traveling to the main objective of the expedition, the Ngozumpa glacier. In the Imja valley, the expedition located ice caves on the Nuptse, Lhotse and Ama Dablam glaciers, and thoroughly explored caves on the latter two (Images. 2 and 3), although mapping was not attempted due to melting conditions and rockfall hazards. The cave shown in Figure 3 still contained a lot of liquid water, partially concealed by a thin skin of ice. Older, higher ice skins formed a series of 'false floors' which provided some moments of excitement. After a period of acclimatization and exploration, the expedition crossed over the Kongma La to Lobuche, where it was hoped to access a large cave on the Khumbu glacier, where the meltstream of the Kangri enters the glacier. This cave had been observed as a large opening on previous visits, but in November 2005 was found to be boulder-choked and inaccessible. Fortunately, however, the meltwater exit point (portal) on the Kangri was open, allowing access to the subglacial cave system. This was mapped in detail, and numerous profiles of the cave cross section were measured.

Attention was then turned to the Khumbu glacier. The largest cave system found on the glacier was located c. 1 km upglacier from Gorak Shep, near the west flank. This cave, named The Amazing Technicolour Yawn, was 192 m in length, and had a strongly meandering planform, following folded crevasse traces. The outermost 80 m of the cave was up to 8 metres high and several metres wide, but then narrowed to a boulder-choked constriction which was barely wide enough to get through (Image 4). Beyond this point, the cave opened out into a high, canyon-like passage (Image 5) which was followed to its termination in a frozen sump. The cave was fully surveyed with tape, compass and clinometer, and detailed floor plans and cross sections were drawn. A second cave was

explored, below the confluence of the Kangri and Khumbu Glaciers. The entrance of this cave had been spectacularly enlarged by warm air currents, and the walls were decorated by innumerable scallop forms (Image 6).

The expedition then crossed over the Cho La to Gokyo, for the final two weeks of fieldwork on the Ngozumpa Glacier. In total, five glacier caves were explored and mapped in detail, with a combined length of over 2 km. The caves exhibited a variety of morphologies, ranging from high, narrow 'canyon-like' tunnels, to wide, low-roofed caves, occasionally opening out into large rooms several metres high and tens of metres across. Phreatic-vadose transitions in passage morphology were commonly observed in the highest elevation passages. Cave passages were surprisingly horizontal and unbranching, typically connecting two relict supraglacial lake basins. Spectacular examples of changing morphologies within a single cave system are shown in Images 7-10, in a cave that was named The Canyons of Your Mind. The initial tunnel was several metres high, with multiple levels separated by narrow slots (Image 7). This then opened out into a broad, arched room with a flat floor coated with a thin layer of sand (The Soccer Field, Image 8). At the far end of the Soccer Field, a jumble of fallen ice blocks appeared to block further progress, but a way through was found (Image 9) into a large room tens of metres across (Image 10). The floor consisted entirely of fallen ice blocks, while the roof was a jumble of semi-detached flakes. This appears to have been ice that has passed through an icefall on the upper glacier, and consists of partially fused seracs. This structurally weak ice has been exploited by englacial meltwater, then subsequently collapsed to create the large room. Thus, fluvial and gravitational processes have combined to open up large voids within the glacier which, presumably will eventually cave in forming a new hollow on the glacier surface. It should be noted that no evidence of active collapsing was noted at this locality during the expedition.

A major scientific finding of the expedition was that all caves exhibited very strong structural control, following structurally deformed debris-filled crevasse-traces. Open crevasses are rapidly filled with the debris that abundantly covers the glacier surface. This debris is predominantly coarse-grained (sand size and larger), as fines appear to be removed by aeolian processes. While crevasses are structurally deformed as they move down-glacier, the permeable granular fill remains intact. Permeability measurements conducted on crevasse fill sampled from the ceilings of upper level cave passages yielded K values in the 10^{-2} to 10^{-3} cm/s range. Granular fill in relict crevasse traces acts as a line of high hydraulic conductivity through otherwise impermeable glacier ice, and serves as inception horizon for conduit development. Despite structural deformation, debris filled crevasse traces are roughly analogous to joints in limestone karst. Indeed, we found that current glacial hydrological theory is inadequate in almost all respects to explain the characteristics and distribution of the caves, and that karst hydrology provides a much more powerful theoretical framework. The failure of traditional glacial hydrological theory to predict the orientation and morphology of englacial conduits on debris-covered glaciers in Nepal highlights a major shortcoming of existing glacial hydrological theory, and emphasizes the value of direct observations of this poorly known but fascinating environment.

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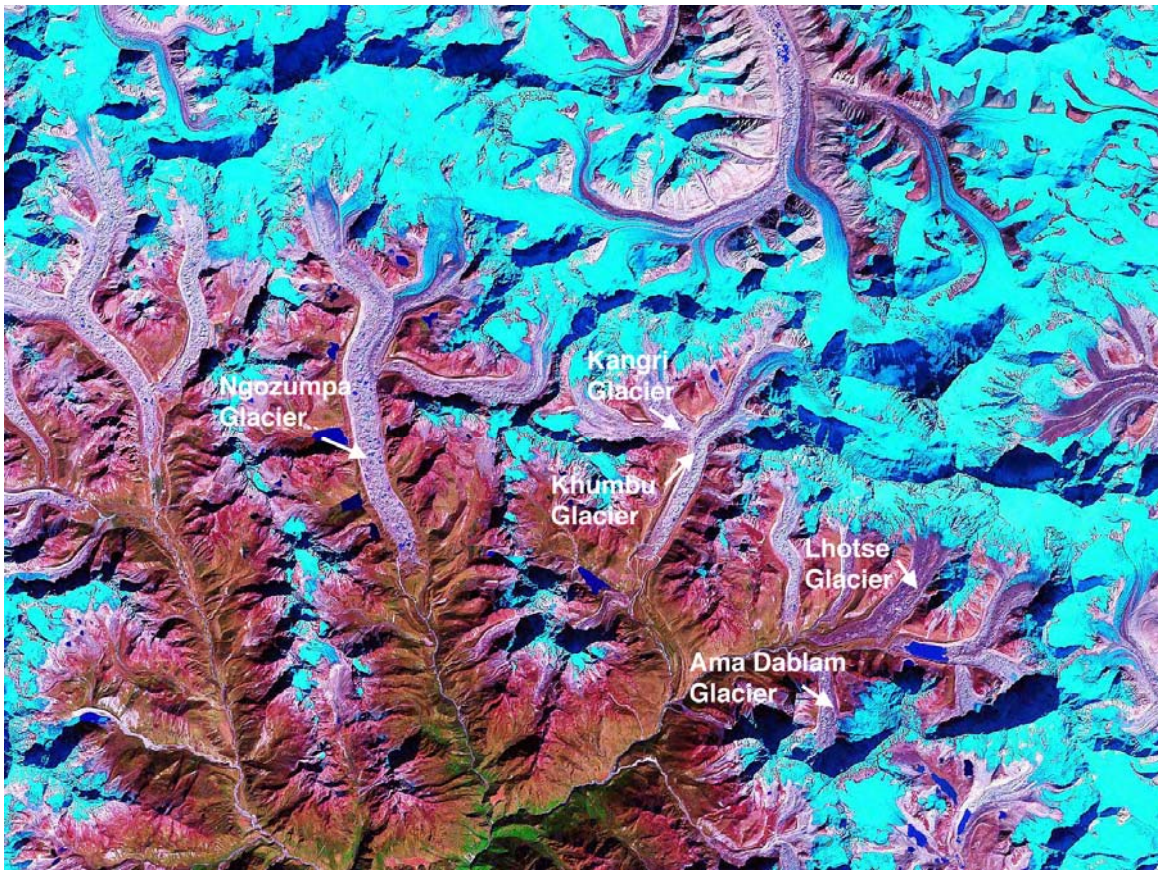

Image 1; Landsat image of the Khumbu Himal, showing the location of glaciers where ice caves were explored and mapped.

Image 2 (Left): Phreatic-vadose transition in an ice cave on the Lhotse glacier
Image 3 (Right): Twin entrances to a u-shaped cave on the Ama Dablam glacier.

Image 4: The narrow constriction in the Amazing Technicolour Yawn, Khumbu Glacier.

Image 5: Large passages, such as this canyon in the Amazing Technicolor Yawn Cave on the Khumbu Glacier, in Nepal, appear to be common features.

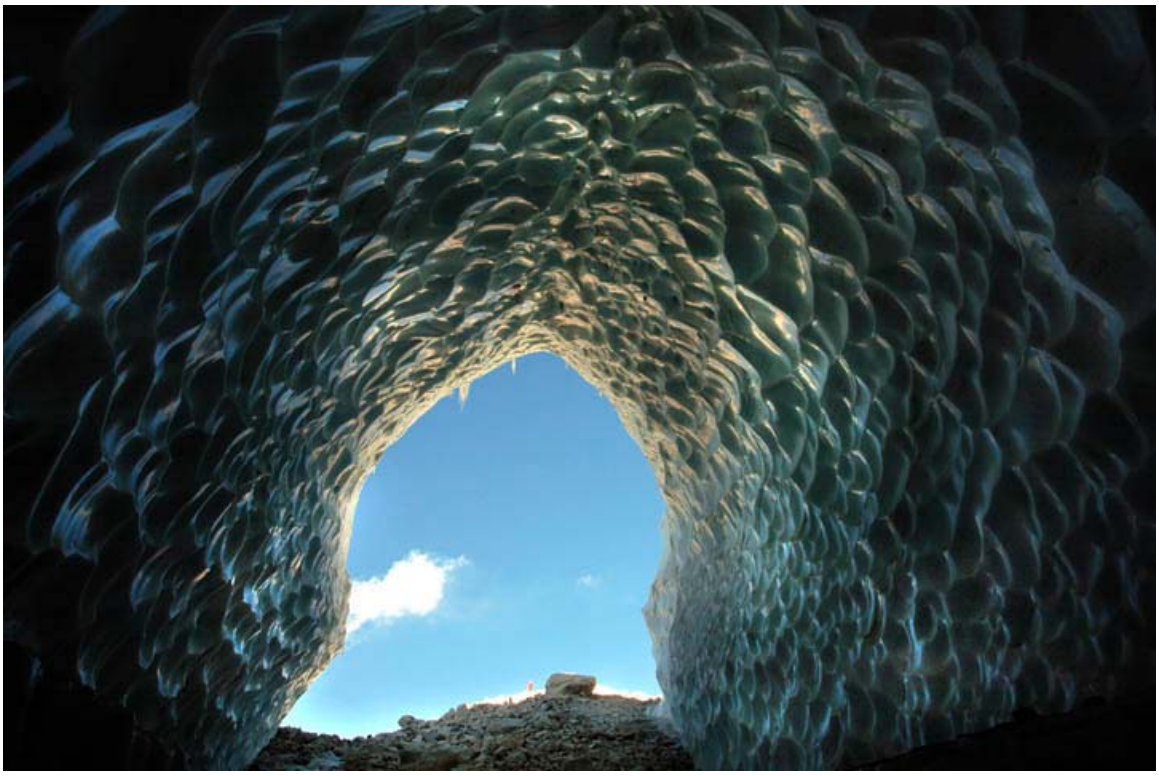

Image 6: Scalloped walls indicate erosion by air currents, responsible for enlarging many tunnel entrances. Figure for scale.

Image 7 (Left): The initial tunnel in The Canyons of Your Mind, Ngozumpa Glacier
Image 8 (Right): The Soccer Field

Image 9: Narrow crawl through collapsed ice blocks, between The Soccer Field and The Reptile Room, Canyons of Your Mind.

Image 10: The Reptile Room, Canyons of Your Mind

Image 11; Wading along Deliverance cave, Ngozumpa Glacier